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FEASIBILITY OF MONITORING FLOW PATTERNS AND SEDIMENT AND POLLUTANT DISPERSION OF WATER BODIES WITH 24-CHANNEL SPECTRAL DATA

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FEASIBILITY OF MONITORING FLOW PATTERNS AND SEDIMENT AND POLLUTANT DISPERSION OF WATER BODIES WITH 24-CHANNEL SPECTRAL DATA

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The primary objective of this research effort was to develop data-handling procedures to transform digital data collected by a Bendix 24-channel airborne sensor into radiance values and to produce images free of skew and reflectance geometry distortion. Data collected over the Chesapeake Bay area on 26 October 1972 and 22 April 1973 at approximately 3200 m and later recorded on computer-compatible tapes (CCT) were studied. Special attention was focused on data from the Rappahannock River. The scanner system, including the mechanics, optics,

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and electronics, is described with an explanation of data formatting on the NASA-generated CCT and the formatting required by existing U. S. Army Engineer Waterways Experiment Station (WES) computer software and programs to handle remotely sensed data, specifically ERIS or LANDSAT CCT data.

Two critical correction problems were encountered, scanning geometry and aircraft attitude. Correction procedures are presented. These were incorporated into a system for 24-channel CCT data conversion by a small computer, PDP 15, and image preparation on an Optronics film writer. A procedure for converting CCT data to radiance at the earth surface was developed, maintaining the relation of radiance to pixel source. Performance problems in the Bendix 24-channel sensor system prevented the completion of an effort to use radiance at the earth surface as a tool to identify varying conditions in or on the water. However, the procedure was developed and has been automated. It is included as an option in the 24-channel data conversion system using the small computer and film writer at WES.

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PREFACE

The study reported herein was conducted with data collected for ERTS Project 281/282- "Hydrodynamic Actions and Delineation of Suspended Sediment Concentrations, Chesapeake Bay Region". It was authorized under the In-House Laboratory Independent Research Program as Project No. 6.11.01.A, 4A061101A91D under appropriation 2142040 408-1506 P611101 S22079, sponsored by the Office, Chief of Engineers. The work was performed during the period August 1973 - June 1975 by personnel of the Environmental Characterization Branch (ECB), Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Messrs. W. G. Shockley, Chief, MESL, and W. E. Grabau, Special Research Assistant and former Chief, ESD, and under the direct supervision of Messrs. J. L. Decell, Chief, ECB, and R. R. Friesz, former Chief, ECB. Miss M. H. Smith was the project manager. The report was prepared by Miss Smith.

COL G. H. Hilt, CE, was Director of the WES during this study and report preparation. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	Metric (SI) to U. S. Customary	
millimicrometres	3.280839×10^{-6}	feet
micrometres	3.280839×10^{-3}	feet
millimetres	0.03937007	inches
metres	3.280839	feet
square metres	10.76391	square feet
cubic metres	6.102376×10^{4}	cubic inches
knots (international)	1.151543	miles (U. S. statute) per hour
milliradians	0.05729578	degrees
radians per second	57.29578	degrees per second
Kelvins	1.8	Fahrenheit degrees*
	U. S. Customary to Metric (SI)	
inches	25.4	millimetres
feet	0.3048	metres
degrees (angular)	0.01745329	radians

* To obtain Fahrenheit readings from Kelvins, use: $F = 1.8(K - 273.15) + 32$.

FEASIBILITY OF MONITORING FLOW PATTERNS AND SEDIMENT AND POLLUTANT DISPERSION OF WATER BODIES WITH 24-CHANNEL SPECTRAL DATA

PART I: INTRODUCTION

Background

1. Within the last several years, new national priorities have made necessary the acquisition and analysis of environmental data on a scale not contemplated heretofore. The regions being considered are so large and the environmental data requirements are so universal that conventional data acquisition systems are no longer adequate to meet the demands. Even systems based on aerial photography and manual interpretation are inadequate in many situations, because processing is too time-consuming and costly.

2. In an attempt to meet this challenge, personnel of the U. S. Army Engineer Waterways Experiment Station (WES), sponsored jointly by the National Aeronautics and Space Administration (NASA) and the Army Corps of Engineers, developed largely automated procedures for using the digital image data acquired by the Earth Resources Technology Satellite (ERTS-1) to obtain certain kinds of environmental data on a regional scale. In general, the procedures based on ERTS-1 data made it possible to very rapidly produce accurate and reliable maps of open-water surfaces and of the concentrations of suspended materials in the surface and near-surface waters.[1,2] Since the analytical procedure for mapping the concentrations of suspended materials depended upon the use of the spectral data defined by the four ERTS-1 spectral bands, it was believed that similar procedures could be used to map the distributions of any other features of the landscape that exhibited unique spectral "signatures." Such features might be expected to include land uses, crop inventories, a limited amount of plant species discrimination (e.g. forest types, aquatic plant species, etc.), certain kinds of topographic expressions, and so on. Thus, a general analytical procedure for exploiting

spectral information would be capable of supplying a significant part of the environmental data required for Corps planning purposes.

3. Despite the fact that the ERTS-1 data proved to be extraordinarily useful in many contexts, it was clear from the beginning that there were situations in which the data would be inadequate. There are two primary reasons. First, the ERTS (and LANDSAT*) pixel[3] is so large (approximately 56.8 by 78.7 m**) that small terrain features are obscured. Since many items of interest to the Corps of Engineers, such as small changes in the positions of shorelines, are much smaller than the ERTS-1 pixel, the satellite view would not meet all Corps data requirements.

4. Second, the ERTS-1 multispectral scanner divides the visible and near-infrared spectrum into only four relatively broad bands (i.e. 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 μm). This means that the ERTS-1 spectral data cannot be used to discriminate between two features that exhibit spectral reflectances that differ only within one band. For example, two tree species might exhibit identical spectra as sensed by ERTS-1, but a close examination of each individual spectrum might reveal that the energy from species A was concentrated in the 0.5-0.6-μm range at 0.51 μm, while that from species B was concentrated at 0.56 μm. Since this kind of situation is common, it seemed obvious that a multispectral scanner that broke the visible and near-infrared spectrum into narrower wavelength bands would provide additional discriminatory power.

5. In view of the factors discussed above, the conclusion was reached that great long-range benefit would be achieved if the concepts developed during the ERTS-based research (see paragraph 2) could be modified and expanded to use digital data obtained with instruments such as the aircraft-mounted, NASA-operated, 24-channel Bendix scanner system. In the development of such a capability, three general problem areas were anticipated.

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* Formerly ERTS.

** A table of factors for converting metric (SI) units of measurement to U. S. customary units and U. S. customary units to metric (SI) units is given on page 4.

a. The ERTS-1 (and LANDSAT) and Bendix 24-channel scanner* digital computer-compatible tapes (CCT) use quite different data storage format, and thus new translation algorithms would be required in order to read the 24-channel data.

b. Because of differences in sensor operating altitudes and mechanical system arrangements and scanning geometry, the distortions inherent in the recorded data are of different kinds and degrees. Thus, algorithms developed to rectify ERTS-1 data would have to be modified, and in some cases, entirely new algorithms would have to be developed.

c. The spectral bands recorded by the BMSS are quite different from those recorded by the EMSS, and the calibration arrangements by which sensor output voltages can be transformed into radiance values are quite different from those in the EMSS; thus, new analytical algorithms would have to be written, even though the general principles would almost certainly be similar.

6. Once it became possible to reliably manipulate the BMSS data so that geometrically acceptable images using radiance values could be produced on a routine basis, the way would be open for the development of spectral analysis procedures. Even though difficulties encountered in manipulating EMSS data suggested that time and funds for the BMSS Study would not be adequate to attempt an actual experiment in spectral analysis, attempts were made to anticipate difficulties that were likely to occur in that area, in the unlikely event that the data manipulation problems required less time than expected.

7. As an example, it was anticipated that the very great differences in the sensor altitudes and scanning geometries of the EMSS and the BMSS would make it impractical to use the same correlation relations between radiance and suspended materials concentrations i r

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* To avoid repetition, the following acronyms will be used: EMSS = ERTS-1 multispectral scanner; BMSS = Bendix aircraft-mounted multispectral scanner.

the BMSS data as were used for the EMSS data.[4] Three major factors could be expected to contribute to the differences.

a. The pixel sizes of the two systems are quite different. The EMSS pixel has an area of about 4470 m^2; whereas, the BMSS, flown at an altitude of about 3000 m, has a pixel covering about 36 m^2 along the ground track of the flight line. Thus, the BMSS would "see" much smaller features than the EMSS. For example, spatially complex features like eddy systems in water may not be detected in EMSS images but may be detected easily in BMSS images.

b. The BMSS scans from -40 to +40 deg with respect to the perpendicular from the scanner to earth, so that the angle of the optical axis of the pixels varies through a range of 80 deg; the range for the EMSS is less than 10 deg. Thus, the reflectance geometries (i.e. the angular relation among light source, terrain surface, and sensor) of the two systems would be quite different. The amount of energy reflected by the same suspended material concentrations in different parts of the BMSS scan swath could well be different, while that of the EMSS could be treated as a constant. There was, therefore, reasonable doubt that simple correlation relations, as used for EMSS data, would be useful for BMSS data.

c. Because of the differences in scanning geometries and sensor altitudes, the optical paths taken by energy quanta in the two systems are quite different. The effects of this were difficult to anticipate.

8. In view of all of these differences and uncertainties, there was considerable doubt that an automated interpretation based on BMSS data would closely resemble one made with EMSS data.

Objectives and Scope

Objectives

9. Primary objective. The primary objective of this research effort was to develop data-handling procedures such that BMSS digital data could be transformed into radiance values and used to produce images free of skew and reflectance geometry distortions. As a practical matter, the objective was to produce the best image possible, from the BMSS digital data using information regarding flight and sensor conditions recorded at the beginning of the NASA-provided CCT.

10. Secondary objective. The secondary objective, to be pursued only if time and funds permitted, was to develop computer software that would make possible the mapping of the distributions of spectrally definitive landscape features, such as concentrations of suspended materials in water, with BMSS data.

Scope

11. The research effort was confined to the use of existing BMSS data and to the use of a PDP-15 computer for basic data manipulation. Essential peripheral equipment was restricted to an Optronics film writer and conventional input-output devices, such as line printers, teletype terminals, and tape and disc drives.

12. Test areas were restricted to the estuaries of the Choptank River in Maryland and the Rappahannock River in Virginia. Data from only one flight line for each estuary were used in the development of computer procedures.

PART II: DESCRIPTION OF 24-CHANNEL SCANNER SYSTEM

Mechanics, Optics, and Electronics

13. The NASA-operated BMSS[5] consists of an aircraft-mounted multispectral scanner and a ground-based data analysis system. The BMSS is an imaging spectrometer that is mounted in a NC-130B aircraft (Figure 1). The Data Acquisition System (DAS) is a ground-based system that processes and rerecords the spectral data on computer tapes and also provides an imagery display of the collected data on a viewing cathode-ray tube (Figure 2).

14. The BMSS scanner collects energy in the spectral range 0.34 to 13.0 μm, which includes the near-ultraviolet, visible, and near-infrared regions of the spectrum. The spectral energy is separated into 24 channels (or wavelength bands) by two grating spectrometers sharing a common scan mechanism. The scanning mechanism is a flat mirror that scans the earth through a slit in the bottom of the scanner and an open door in the bottom of the aircraft. The mirror rotates counterclockwise with respect to the aircraft heading providing left-to-right pixel scanning, while the forward motion of aircraft provides a sequential line-by-line scan of the earth below. The scanning mirror views the earth through 80 deg and completes a 360-deg rotation, during which it senses four calibration sources (Figures 3 and 4). During the earth scan the reflectance from each of 700 pixels is processed, and the response of each of 24 sensors to a pixel reflectance is recorded on magnetic tape. According to the NASA training manual,[5] the calibration sources are expected to permit calibration of the spectral data to a high degree of accuracy. A precise ratio of aircraft velocity (V) to height (H), V/H, must be maintained to obtain the normal scan relation, i.e. adjacent scan lines just touching each other along the ground track (the center of the scan swath). To provide this normal scan, the scan motor speed is established in terms of V/H.

15. The scan mirror is set at a 45-deg angle with respect to the aircraft longitudinal axis. The scan mirror reflects radiant energy from the ground and from the calibration sources to a Dall-Kirkham telescope. A roll-rate gyro is used to maintain the scanner field-of-view (FOV) constant regardless of aircraft roll (within ± 8 deg). The Dall-Kirkham telescope transmits the reflected energy through a system of mirrors and a 0.2286-cm aperture onto a series of dichroics and grating spectrometers, which separate energy of wavelengths less than 2 μm from those of 2 μm and greater (Figure 5). The aperture is dimensioned to define within the center of the received energy field a FOV of 2 mrad. Figure 6 shows the path of the short wave reflected energy to reach the detectors.

16. Scanning in a left-to-right rotation, the mirror first scans the earth surface, then the calibration source elements in this order: 16 calibration elements from sensor exposure to the calibration instrumentation housing (not used), 16 from the UV-VIS-IR (ultraviolet-visible-infrared) integrating sphere, 16 from the sky radiance tube, 16 from the high-temperature blackbody, and finally 16 from the low-temperature blackbody. Figure 7 is a simplified block diagram of the complete system. Figure 8 shows the calibration grating and timing sequence in the scan rotation. The UV-VIS-IR integrating sphere establishes the maximum radiance, and the low-temperature blackbody the minimum radiance, for the scan.

17. The same detection procedures are applied to radiance from calibration sources as from earth elements; therefore, the calibration radiance value for a scan and the recorded pixel radiance from each channel are on the same basis. Figure 9 illustrates the reflectance from the scan pixels as the earth is scanned through 80 deg and the corresponding reflectance for each channel in the calibration sources as the 360-deg rotation is completed.

18. The UV-VIS-IR sphere (Figure 10) is a 16-in.-diam aluminum sphere painted with high-reflectance paint and illuminated from the side by a 200-w tungsten halogen lamp. The scan mirror views the illuminated sphere through a large, plain optical glass window and "sees" a

diffused surface of supposedly known spectral radiance. The radiance emitted from the sphere covers the range 0.3 to 2.5 μm and is calibrated prior to flight to a standard lamp (QB #11) of known radiance per wavelength band (Table 1).

19. The sunlight-matching part of the UV-VIS-IR calibration contains a filter wheel with eight different neutral-density attenuation screens, which is located between the lamp and the UV-VIS-IR sphere and provides a means of changing the spectral intensity to match the sunlight conditions during a data run. This equipment was not operational during the data runs investigated in this study.

Data Tape Format

20. The 24-channel data are in the universal format as defined by NASA.[6] The 24 channels of data are digitized into 8-bit words and recorded on 12 tracks of a 14-track tape recorder. Two consecutive channels of scanner data are interleaved onto one tape track; the first is referred to as the odd channel, and the second is referred to as even. Calibration sources, aircraft information, such as altitude and location, and other housekeeping information are multiplexed together and recorded on the 13th track. The 14th track contains the time code signals. The data are direct-recorded in Manchester (Bi-phase-L) code.

21. Nine-track CCT containing these data were requested from NASA. The CCT header record contains the information in the house-keeping and the auxiliary data annotation set ([illegible]) recorded on the original tapes (Figures 11 and 12). A program was written to present these data in a more usable form (see paragraph 31). An example is shown in Table 2. Note the channel order of data requested by the user is all odd channels in sequence followed by all even channels in sequence ([illegible] group in Table 2). This is the order of data on CCT received from NASA. Following the header record are the requested data scans. [illegible] 700 samples, followed by 80 calibration samples

for each channel (Figure 13). Data are interleaved by bands in each sample, two channels to a data word.

22. For seven channels, each scan on the CCT contains 5460 8-bit bytes of data (43,680 bits). The 80 calibration samples are from the four calibration sources (see paragraphs 14-16) plus a spare (16 samples each). Data from two of the calibration sources, the integrating sphere and the low-temperature blackbody, are used to establish the range of reflectance reception by each channel at the time of the scan.

PART III: RESEARCH PLAN

Introduction

23. When solar energy strikes the earth's surface, it is reflected, absorbed, and combined with energy emitted by the earth (Figure 14). As it passes through the atmosphere, solar energy is subjected to scattering and absorption, thus limiting the amount of radiation incident upon the earth. The set of curves in Figure 15 shows the varying amounts of absorption at different wavelengths of the spectrum. The top curve, m = 0, is the spectral curve of irradiance before it enters the earth's atmosphere. The m = 1 curve describes the solar irradiance at sea level when the sun is directly overhead. The other curves illustrate the situation at various sun angles. The figure shows that the larger the sun angle, the greater is the attenuation of energy. This results from the longer paths through the atmosphere; the closer the sun is to the horizon, the greater is the amount of atmosphere that the rays must penetrate.

24. Figure 16 shows radiance transmission through the atmosphere. The dips show the areas in which absorption has taken place due to water vapor, carbon dioxide, ozone, molecular oxygen, and Rayleigh and aerosol scattering.[5] The nodal wavelengths of each of the 24 channels (or wavelength bands) are indicated in the figure and are defined in Table 3. Note that 5 of the 24 channels fall within the visible spectrum, and that 11 cover the entire range of visible and near-visible wavelengths (0.35 to 1.1 µm). This study considers channels 4-10 which closely parallel the range of wavelength bands received by the ERTS sensors (Table [illegible]).

25. Clear water that is free from suspended sediments reflects most of the blue-green and green portions of the spectrum and absorbs the other visible radiant energy. In the near-infrared portion of the spectrum (0.8-1.1 µm), almost all energy is absorbed by water. A record [illegible] from the earth surface in this portion of the spectrum can define approximately the land-water interface of a water body. The

resolution of the interface is determined by the size of the ground element (pixel) defined by the field of view of the scanner; and since the total radiance from a pixel may be partly from water and partly from nonwater or from wetted soil, a clear definition of the water's edge is not possible. Although absolute definition is impossible, good approximation can be made within the dimensions of two pixels in length and width.

26. Suspended material in water causes changes in the amount of reflectance and in the variety of reflected spectral energy, i.e. the amount of energy at various wavelengths. Theoretically, these changes are associated with the amount and kind of suspended material. This theory was supported by WES investigation of data obtained from ERTS-1 overpass in the Chesapeake Bay.[2]

27. Considering these facts and theories, a research plan was developed which fell naturally into two parts which are illustrated schematically in Plates 1 and 2. Plate 1 describes the plan to convert 24-channel data recorded on NASA CCT to WES computer program formats and to write, analyze, and correct geometric distortion when images are written from that data using the WES film writer. Plate 2 describes the plan to develop the analytical procedures required to map spectrally defined regions. In this context, a spectrally defined region (i.e. a patch of landscape that displays a unique combination of radiance values in some selected set of wavelength bands) is one that has a specified concentration of materials suspended in water. In the plates, the blocks tracing the various stages are numbered sequentially; the subsequent discussions are keyed to the relevant block numbers in the plates.

Anticipated Problem Areas

28. The BMSS scanning geometry is quite different from that of the EMSS and, in consequence, quite different kinds of geometric distortions were expected to occur (Block 12, Plate 1). The anticipated distortions are of two major kinds.

a. Scanning geometry. The aircraft was flying at an approximate altitude of 3050 m during the missions used in this study. Since the scanner swings through an arc of 80 deg, the ground swath covered by the scanner is about 5118 m wide. Since the solid view angle of the scanner is fixed, the pixels at the edges of the scan swath will be much larger than the pixels along the center of the scan swath. The Optronics film writer, which is used at WES to write images from digital data, writes a square pixel of fixed size, and thus a direct transcription of the BMSS data onto film with the film writer will result in a narrower swath than the true scanned swath. It was clear that this distortion would have to be removed.

b. Aircraft attitude. While aircraft roll was automatically compensated for by on-board platform stabilization, aircraft yaw, if any, could be expected to introduce skew into the image. Since it was almost certain that there would be some wind from the side, the aircraft heading would diverge to some degree from the line of flight. A procedure would be needed for transforming the BMSS tape data arrays to correct for this effect.

29. The calibration relations by which transducer voltage values (digital form on CCT) can be transformed into radiance values (Block 10, Plate 1) in the BMSS system are different from the relations used for the EMSS system. Thus, new calibration transforms would be required.

30. One major problem was that there was no possibility of determining the actual suspended materials concentrations in the waters of the test areas during the time of the aircraft overflights. This would have required teams in boats collecting water samples, and this was far too costly to be practical. As a result, there was no possibility of establishing an empirical relation between suspended materials concentration and radiance (Block 18, Plate 2) as had been done previously for the studies using the EMSS.[2] The best that could be hoped for was a

relation that described relative differences in suspended materials concentrations, based on the fact that low concentrations of suspended materials appear to produce direct linear correlations with radiance.[2]

PART IV: DEVELOPMENT OF DATA HANDLING PROCEDURES

Data Conversion Software

Blocks 1 and 2, Plate 1

31. With the help of Reference 6, a computer program was written that decoded the BMSS CCT and reassembled the contained data into forms more readily usable by WES computer hardware and available software. Several modules were involved. For example, the NASA tapes contain housekeeping data (Figure 11), aircraft location and attitude data (Figure 12), radiant energy data from terrain, and calibration data. These data were all reformatted so that they could be printed out in a more readable form, as illustrated in Table 2.

32. Another module was designed to transform the scanner transducer data (i.e. the output of the sensors that measure the amount of energy received by each BMSS wavelength band) into the format required by the WES Optronics film writer. This format is illustrated in Figure 17. The general principle is that a new tape is devoted to four wavelength bands or dummies so that each wavelength band can be processed independently with existing WES software.

Test Site Selection

Blocks 3 and 4, Plate 1

33. In the prior work with ERTS-1 data, maps were produced of suspended materials concentrations in several estuaries leading into Chesapeake Bay.[2] Of the several available, the Rappahannock and Choptank estuaries were chosen. The Rappahannock River estuary was chosen because it has sources of relatively uniform suspended materials and a small tidal range. For contrast, the Choptank River estuary was chosen because its sources of suspended materials are quite complex, and its tidal range is somewhat greater than that of the Rappahannock. The locations of the selected study areas are shown in Figure 18. BMSS tapes covering these areas were ordered from NASA.

Data Transformation

Blocks 5, 6, and 7, Plate 1

34. Once the programs to read and reformat the NASA BMSS tapes had been written, the NASA tapes covering the BMSS records for the two test areas were reformatted (Block 5) into WES Optronics film writer format (Figure 17). At this stage, the contained data have not been transformed in any way. The data relevant to scanner pixels are still raw digital values defining transducer output voltages, and the array is a simple and rigid raster array. If used to drive the Optronics film writer, the resulting image would include all of the distortions introduced by scanning geometry, aircraft yaw, and so on.

35. In addition, all housekeeping data (Block 6), calibration data (Block 7), and so on, were extracted and assembled into tables as illustrated in Table 2. Among the critical information are those items describing flight parameters. Of particular importance are the time, location, radar altitude (which is a measure of absolute height above the terrain), true heading, drift, and date. The significance of these parameters will be discussed later.

Water-Land Discrimination

Blocks 8 and 9, Plate 1

36. Because the secondary objective (see paragraph 10) involves the distributions of suspended materials in water, it was obviously advantageous to delete all nonwater areas from the reformatted BMSS tapes, since this would result in a significant saving of processing time. To achieve this, the water-land discrimination program developed for use of EMSS data[2] was used without modification. When used with EMSS data, the discrimination between water and land is made with the near-infrared band (ERTS-1 channel 7; 0.8-1.1 μm), since all energy in this wavelength band is nearly totally absorbed by water, while it reflects strongly from vegetation, soil, and other "land" materials.

37. The properties of ERTS-1 channel 7 are most closely approximated by those of BMSS channel 10 (0.981-1.045 μm, Table 3), and this wavelength band was therefore used to define the pixels relating to open water surfaces. This information was then used as a "digital mask" (see procedure described in Reference 2) to edit out all "land" areas in all of the wavelength bands used in this study (Block 8) (BMSS channels 4-10).

38. Despite the fact that the imagery resulting from writing the raw tapes is badly distorted, it is helpful to write an image of each wavelength band (Block 9), simply to confirm that all decoding and reformatting procedures have operated correctly (Figure 19). Even an uncritical comparison of the image with a map of the corresponding area (Figure 20) will reveal that the geometry is badly distorted.

Voltage-to-Radiance Transformation

Blocks 10 and 11, Plate 1

39. Using the reformatted data and the calibration data contained on the BMSS tapes, a program was written that transformed the values recorded by the BMSS into radiance values. Since calibration data varied considerably, no attempt was made to develop a conversion equation in which constants were applicable to the entire data set. Instead, a conversion based on the data from calibration sources from each scan was derived and applied to that scan only.

$$R_{ij} = \left[\frac{Pix_{ij} - \overline{S5}_j}{\overline{S2}_j - \overline{S5}_j}\right]\left[\frac{1}{\rho j}\right]\left[(RSL_j)\ (B_j)\right]\left[\frac{1}{\tau}\right]\left[\cos \overline{SA}\right]$$

where

i = pixel in a scan

j = channel, i.e. channel 4, 5, 6, 7, 8, 9, or 10

R_{ij} = radiance at earths surface of i^{th} pixel in channel j

Pix_{ij} = recorded digital value of reflectance from i^{th} pixel in channel j

$\overline{S5}_j$ = average of 16 samples from the low-temperature blackbody for channel j for a scan

$\overline{S2}_j$ = average of 16 samples from the integrating sphere for channel j for a scan

ρ_j = percent reflectance with which the integrating sphere compares to the standard lamp for channel j

RSL_j = spectral radiance evaluation of the standard lamp per micrometer for channel j

B_j = channel width of j^{th} channel

τ = atmospheric transmittance factor

$\overline{SA}$ = sun angle from nadir (perpendicular from sensor to earth)

For each data collection run. (ρ_j) $((RSL_j)(B_j))$ $(1/\tau)$ $(\cos \overline{SA})$ for each channel is constant.

Image Geometry Correction

Blocks 12, 13, 14, and 15, Plate 1

40. Two major kinds of geometric distortions occur in the BMSS data; namely, that caused by aircraft crabbing or yaw (i.e. the angular relation between aircraft heading and the ground track of the aircraft) and that caused by the scanning geometry (see paragraph 28a).

41. The procedure used to correct for aircraft crabbing is illustrated in Figure 21. Line A'B' in Figure 21a indicates the actual scan relation to the center line (i.e. the true course of the ground track of the aircraft) of the scene. The orthogonal grid array of data on the BMSS tape places the scan line at 90 deg to the scene center line (line AB in Figure 21a and b), which causes a misplacement of features as indicated in Figure 21c. The displacement at each end of the scan can be computed from the difference in the true heading and

true course. By staggering blocks of pixels across the scan in a diagonal array down scans (Figure 21d and e), features are adjusted to their normal relation to each other and to the center line of the scene. The geometrics illustrated by Figure 21a-e were reduced to a computer program that rearranges the pixels in an orthogonal grid such that, when written with the film writer, the skew created by aircraft crabbing is eliminated. An example of this type of correction is given in Figure 22. Note that after the correction, the ends of the views are not at right angles to the center line.

42. A quite different procedure is required to compensate for the variation in pixel width as the instantaneous viewing angle is removed from the center line (Figure 23). At nadir the instantaneous FOV (2 mrad) is 6.1 m (20 ft) wide when the aircraft is flying at an altitude of 3048 m (10,000 ft). The 24-channel Earth Observations Aircraft Program flight over the Rappahannock on 22 April 1973 was flown at [illegible] m (10,950 ft), which defines the pixel width at nadir as 6.67 m ([illegible] ft). Each successive pixel is wider as the scanning angle from the center line increases. The pixel viewed at the scan extreme is "seen" at an angle of 40 deg from the center line and is [illegible] m wide. Since there is nothing in the matrix of tape data to indicate the spatial relations between the earth pixels from which data were drawn, some corrective procedure applied to the [illegible] scan arrays was necessary. To stretch the scan array of data, pixel radiance values were repeated at logical points. These points were determined by comparing the difference in distances from the nadir point when computed using the tangent of the scanning angle and the altitude of the sensor and when computed using the number of pixels from nadir and the width of the pixel at nadir. When the difference in these distances exceeded the width of the pixel at nadir, the radiance value was repeated expanding the number of pixels in the scan. This expanded scan pushes the scan extremes to more nearly coincide with the earth location sensed by the extreme instantaneous FOV. In Figure [illegible], pixel 75 has been repeated. The farther away from the center line, the more often pixels are repeated. In the Rappahannock

digital map, 70 pixels were added to each half of each scan. The geometrics of this situation were also reduced to a computer program. An example of a scene before and after correction for scanning geometry is given in Figure 24. Note that after correction the scene is significantly wider than before correction. It is usually helpful, as illustrated in Figure 24, to write an example of the scene in each wavelength band to verify that the programs have operated properly.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Primary objective

43. The primary objective was achieved. A set of computer programs is now available that transform the NASA-provided BMSS CCT into an image formed of radiance values and free of both skew and scanning geometry errors. All programs are run on a IBP-15 computer, and images are produced directly with an Optronics film writer. Thus, the NASA BMSS tapes can be used effectively by agencies having only very modest computer facilities to create pictures of areas of the earth's surface and its radiance.

Secondary objective

44. A good deal of progress has been made toward the secondary objective, but the work has not been brought to a successful conclusion. The results of this effort will be reported, [illegible], in a separate paper. Some significant [illegible] about distortions in remotely sensed data that have been [illegible] in the pursuit of the secondary objective need further study. There is the problem of increased radiance due to changing slope angle of the surface, which overlays the radiance due to the property of the water itself. There are other distortion factors, such as bottom reflectance and the depths to the bottom at which that reflectance is [illegible].

Recommendations

45. It is recommended that study of the [illegible]-channel data continue in an effort to develop techniques to reduce distortion caused by extraneous radiance which [illegible] to that due only to the properties of the water itself.

46. It is recommended that [illegible] the secondary objective [illegible] equipment [illegible] wavelength, 0.5[illegible]1.04 [illegible].

The Bendix 24-channel sensor has been abandoned in favor of the Bendix 11-channel sensor because of the more consistent performance of components, less sensor "noise", and better control of the internal flight environment. The channels investigated in this study are included in the Bendix 11-channel sensor equipment with the same channel wavelength ranges and same type receptors. It is recommended that this study be repeated with existing data collected by the Bendix 11-channel sensor over water bodies.

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2. Williamson, A. N., "Movement of Suspended Particles and Solute Concentrations with Inflow and Tidal Action," Technical Report (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Grabau, W. E., "Pixel Problems," Miscellaneous Paper (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

4. NASA/Goddard Space Flight Center, "ERTS Data Users Handbook," 1972, Greenbelt, Md.

5. National Aeronautics and Space Administration, "NASA 24-Channel Multispectral Scanner System Training Course," Information Systems Division, Manned Space Flight Center, Houston, Tex.

6. National Aeronautics and Space Administration, "Earth Resources Data Format Control," PHO-TR543, Vol I, May 1973, Manned Space Flight Center, Houston, Tex.

Table 1

Calibration Data for Standard Lamp (QB #11)

Wavelength μm		Spectral Radiance w/sr/μm/cm^2	
(1)	0.325	(1)	2.65×10^{-4}
(2)	0.350	(2)	6.48×10^{-4}
(3)	0.375	(3)	1.22×10^{-3}
(4)	0.400	(4)	1.89×10^{-3}
(5)	0.425	(5)	2.87×10^{-3}
(6)	0.450	(6)	3.95×10^{-3}
(7)	0.475	(7)	5.07×10^{-3}
(8)	0.500	(8)	6.25×10^{-3}
(9)	0.525	(9)	7.35×10^{-3}
(10)	0.550	(10)	8.16×10^{-3}
(11)	0.575	(11)	9.38×10^{-3}
(12)	0.575	(12)	1.01×10^{-2}
(13)	0.6375	(13)	1.11×10^{-2}
(14)	0.675	(14)	1.19×10^{-2}
(15)	0.700	(15)	1.22×10^{-2}
(16)	0.725	(16)	1.27×10^{-2}
(17)	0.750	(17)	1.29×10^{-2}
(18)	0.775	(18)	1.30×10^{-2}
(19)	0.800	(19)	1.33×10^{-2}
(20)	0.900	(20)	1.25×10^{-2}
(21)	1.0	(21)	1.22×10^{-2}
(22)	1.1	(22)	1.13×10^{-2}
(23)	1.2	(23)	1.02×10^{-2}
(24)	1.3	(24)	8.91×10^{-3}
(25)	1.6	(25)	5.33×10^{-3}
(26)	1.9	(26)	2.78×10^{-3}
(27)	2.2	(27)	1.28×10^{-3}
(28)	2.5	(28)	5.41×10^{-4}

Table 2

Information Extracted From Rappahannock River Tapes

Record Size 156
No. of Elements 700
Channel No. 5
Channel No. 7
Channel No. 9
Channel No. 4 *
Channel No. 6
Channel No. 8
Channel No. 10
Scan Status 255
Starting Scan Line 66331
Time 16:46:19.3
Latitude N37 deg 37.3 min
Longitude W 76 deg 28.5 min
Radar Altitude 10950
Barometric Altitude 36800
True Heading Deg. 285.5
Drift Deg. L Than Course 1.4
Roll Rt. Wing D Deg. 0.7
Pitch Nose D Deg. 0.2
Ground Speed 271 kts
Date 4-22-73
Mission 230
Site 244
Flight 22
Line 3
Run 1
Voltage Gain and Level

Chan 1	Gain 1	Level 0
Chan 2	Gain 1	Level 0
Chan 3	Gain 1	Level 0
Chan 4	Gain 1	Level 0
Chan 5	Gain 1	Level 0
Chan 6	Gain 1	Level 0
Chan 7	Gain 1	Level 0
Chan 8	Gain 1	Level 0
Chan 9	Gain 1	Level 0
Chan 10	Gain 1	Level 0
Chan 11	Gain 1	Level 0
Chan 12	Gain 1	Level 0
Chan 13	Gain 1	Level 0

(continued next column)

(continued)

Chan 14	Gain 1	Level 0
Chan 15	Gain 1	Level 0
Chan 16	Gain 1	Level 0
Chan 17	Gain 1	Level 0
Chan 18	Gain 1	Level 0
Chan 19	Gain 1	Level 0
Chan 20	Gain 1	Level 0
Chan 21	Gain 1	Level 0
Chan 22	Gain 1	Level 0
Chan 23	Gain 1	Level 0
Chan 24	Gain 1	Level 0

Chan 1	Reflectance Calibration 0
Chan 2	Reflectance Calibration 0
Chan 3	Reflectance Calibration 0
Chan 4	Reflectance Calibration 0
Chan 5	Reflectance Calibration 0
Chan 6	Reflectance Calibration 0
Chan 7	Reflectance Calibration 0
Chan 8	Reflectance Calibration 0
Chan 9	Reflectance Calibration 0
Chan 10	Reflectance Calibration 0
Chan 11	Reflectance Calibration 0
Chan 12	Reflectance Calibration 0
Chan 13	Reflectance Calibration 0
Chan 14	Reflectance Calibration 1
Chan 15	Reflectance Calibration 1
Chan 16	Reflectance Calibration 1
Chan 17	Reflectance Calibration 1
Chan 18	Reflectance Calibration 1
Chan 19	Reflectance Calibration 0
Chan 20	Reflectance Calibration 0
Chan 21	Reflectance Calibration 0
Chan 22	Reflectance Calibration 0
Chan 23	Reflectance Calibration 0
Chan 24	Reflectance Calibration 0

Low-Temp. Range 2
Control-Temp. Range 1
Internal Reflectance 1
Roll-Gyro Alignment 0

*Channel order of data requested by user.

Table 3

BMSS Channel Characteristic Bands Compared to EMSS Bands

BMSS CHANNEL	BMSS ARRAY	BMSS BAND	BMSS CENTER	EMSS CHANNEL	EMSS BAND
1	0	0.375-0.405	0.394		
2	0	0.40-0.44			
3	0	0.466-0.495	0.474		
4	1	0.53-0.58		4	0.5-0.6
5	1	0.588-0.643	C.623		
6	1	0.65-0.69		5	0.6-0.7
7	1	0.72-0.76			
8	1	0.770-0.810	0.792	6	0.7-0.8
9	1	0.82-0.88			
10	1	0.981-1.045	0.999	7	0.8-1.2
11	2	1.20-1.30			
12	2	1.533-1.62	1.55		
13	3	2.3-2.43	2.35		
14	3	3.78-4.04			
15	3	4.50-4.76	4.63		
16	4	6.0-7.0			
17	4	8.27-8.7	8.53		
18	4	8.8-9.3			
19	4	9.38-9.876	9.62		
20	4	10.1-11.0	10.58		
21	4	11.0 12.0	11.4		
22	4	12.0-13.0	12.4		
23	2	1.133-1.170	1.152		
24	1	1.06-1.095			

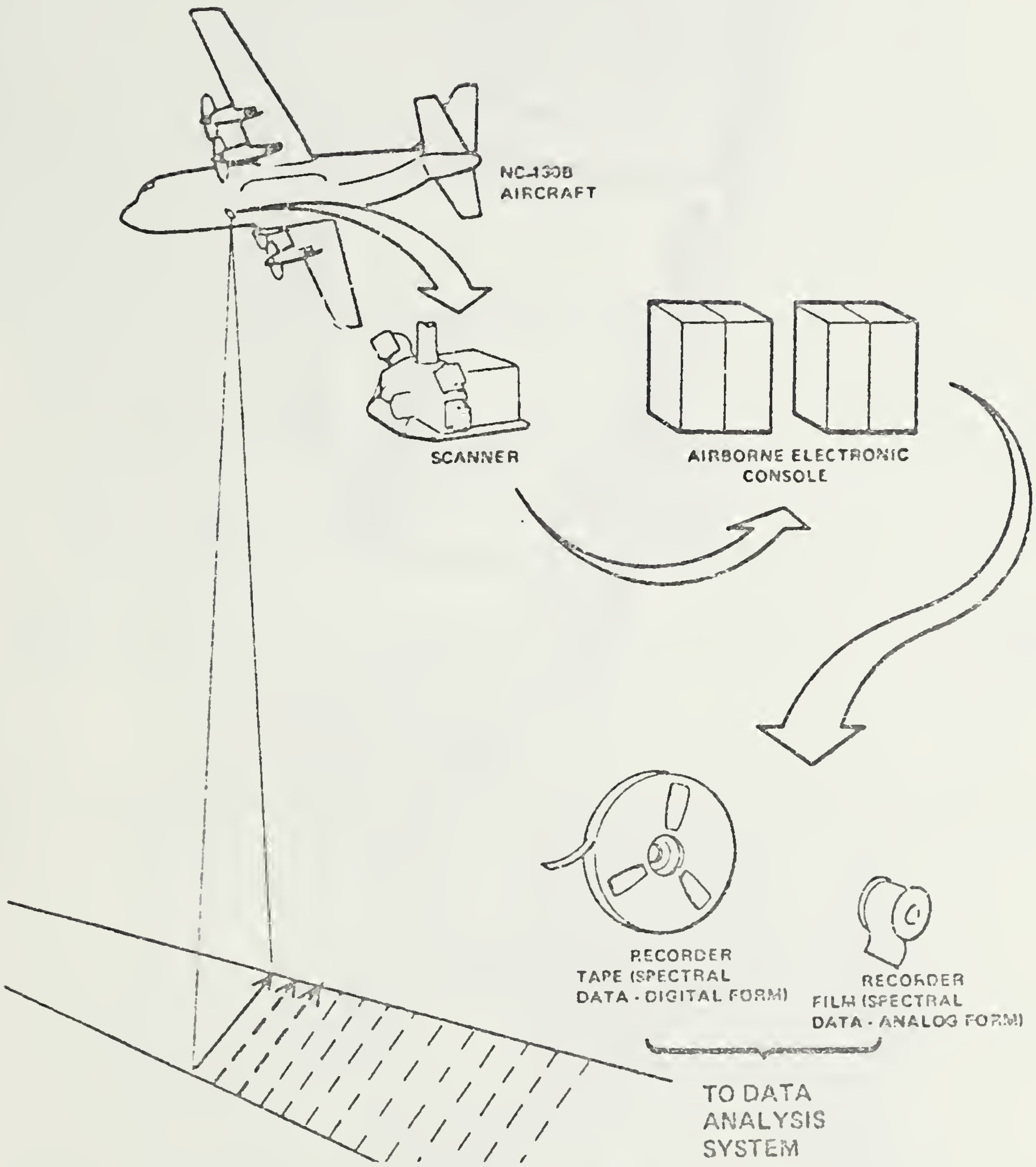


Figure 1. Airborne multispectral scanning system[5]

Figure 2. Ground-based data analysis system[5]

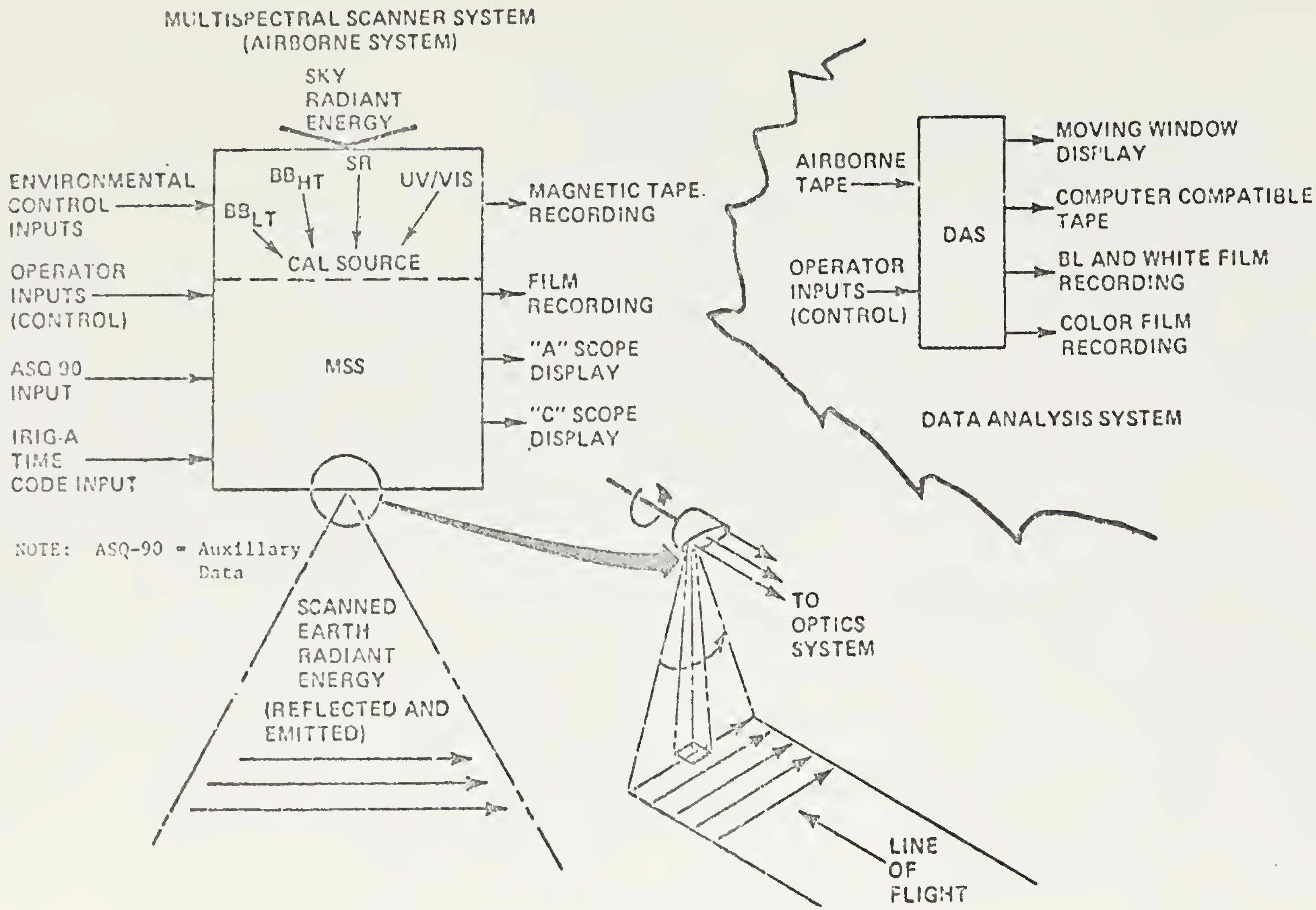
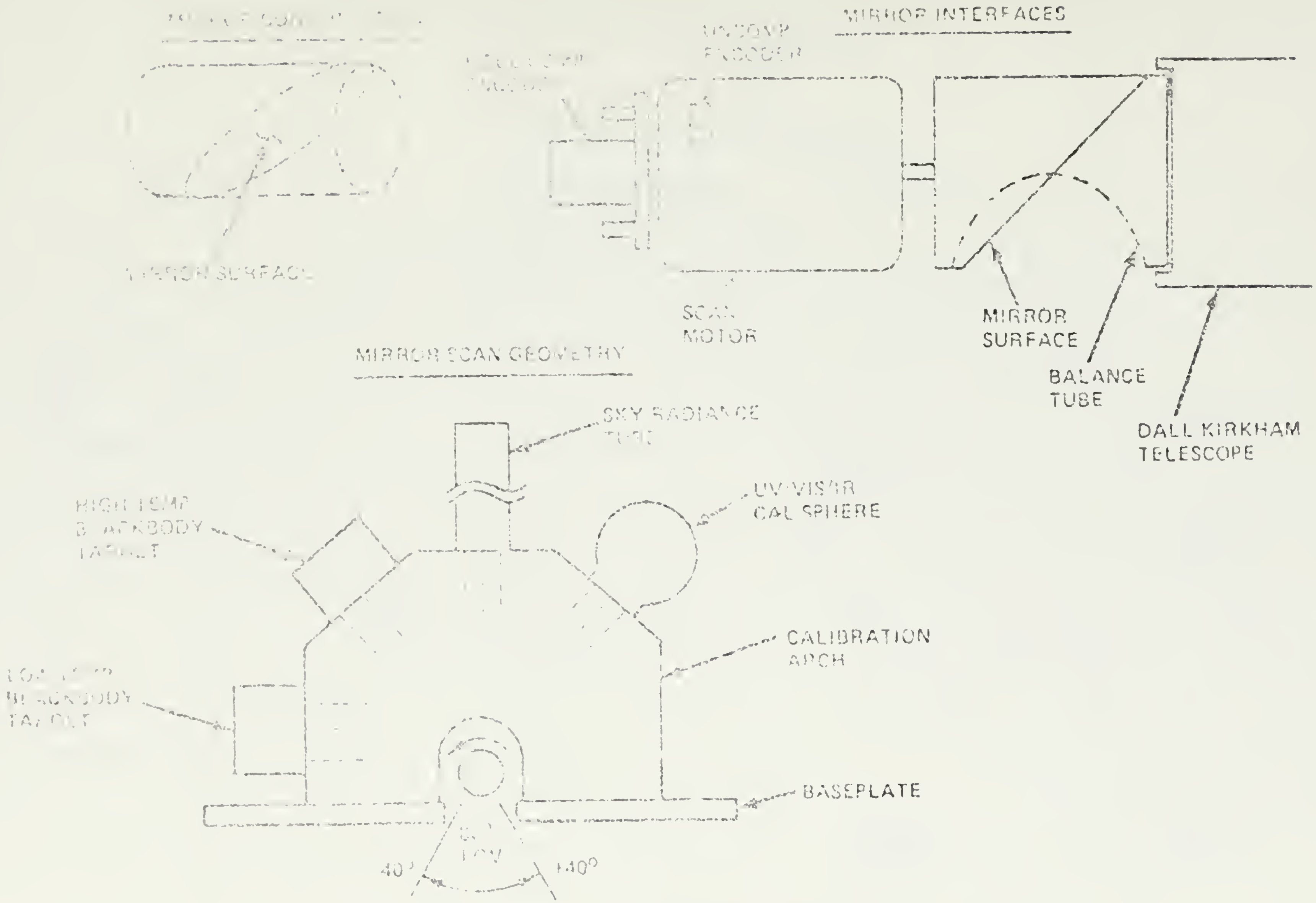


Figure 3. Multispectral data system block diagram[5]



MIRROR INTERFACES
SCAN MOTOR
MIRROR SURFACE
BALANCE TUBE
DALL KIRKHAM TELESCOPE
MIRROR SCAN GEOMETRY
SKY RADIANCE
UV-VIS-IR CAL SPHERE
CALIBRATION ARCH
BASEPLATE
BLACKBODY
40°
40°

33

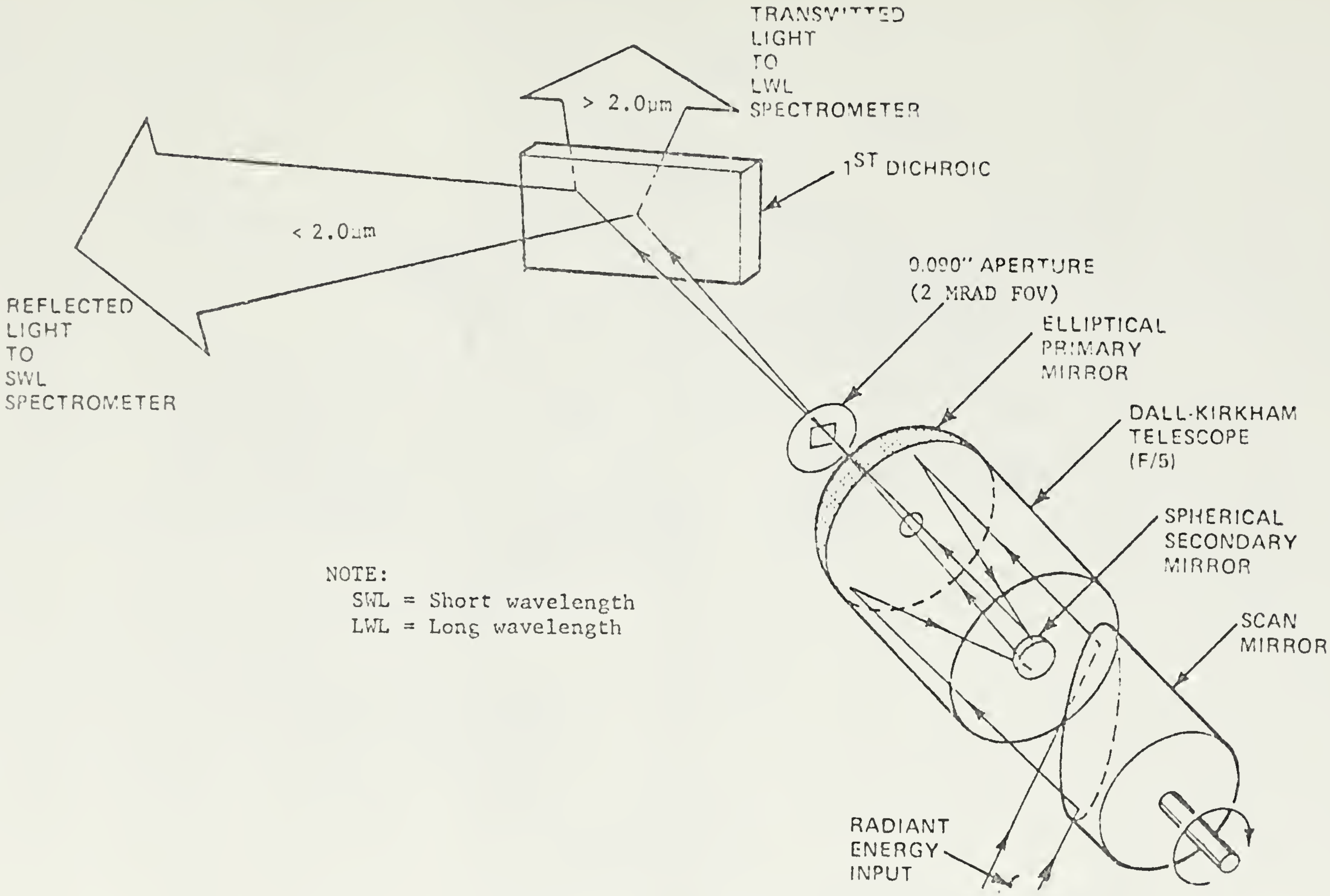


Figure 5. Schematic diagram of collecting optics[5]

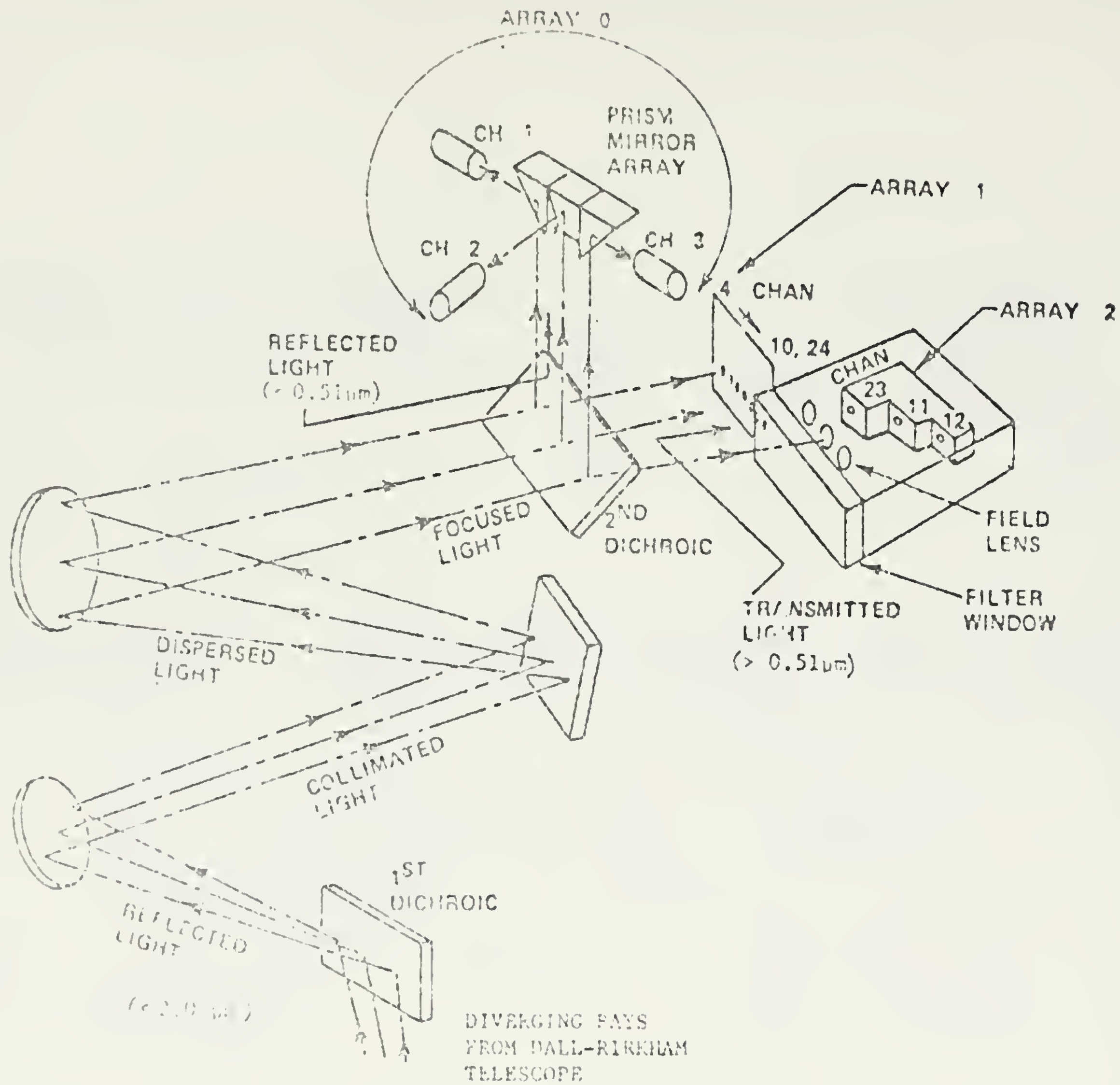


Figure 6. ... diagram of short wavelength spectrometer and detectors[5]

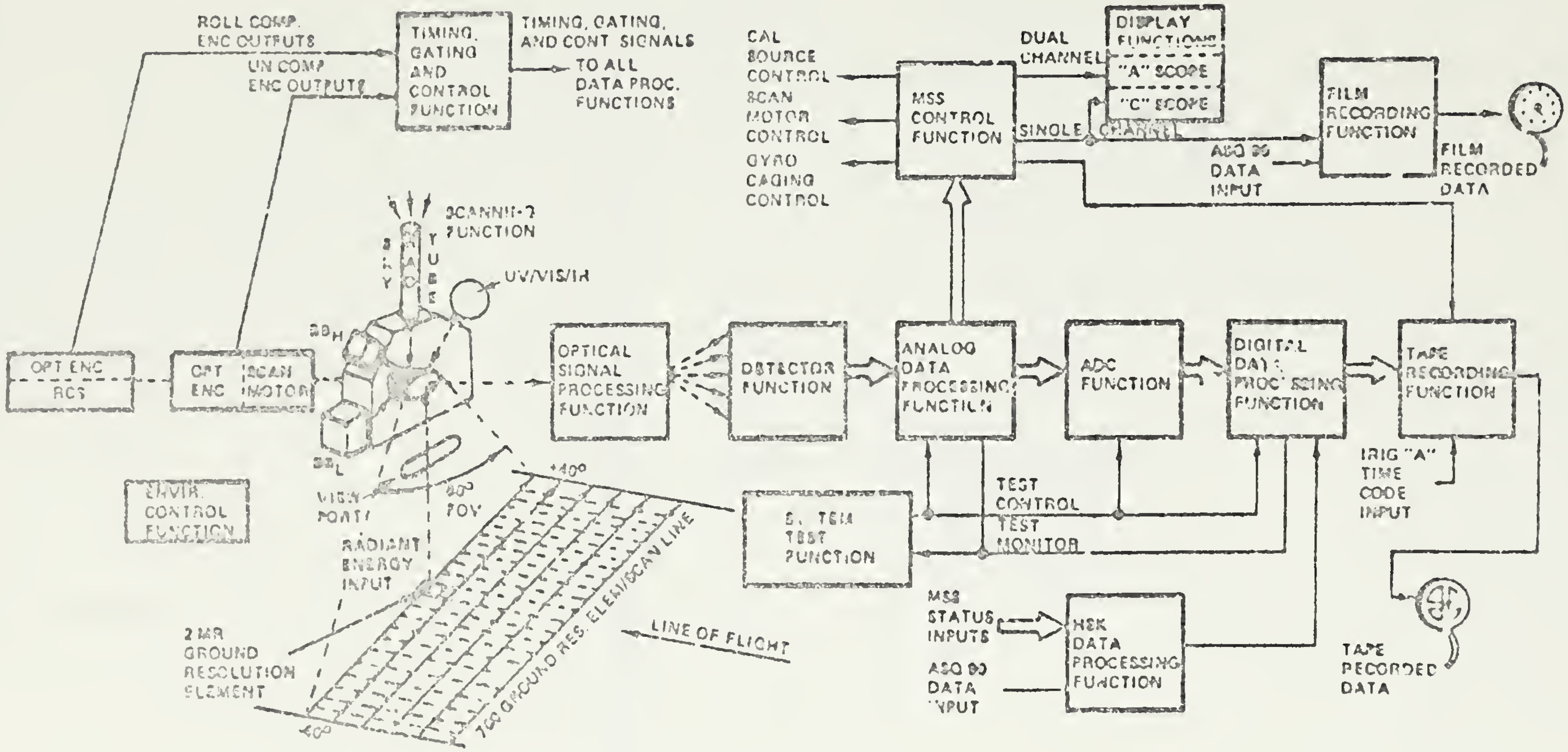


Figure 7. Simplified basic multispectral sensor function diagram[5]

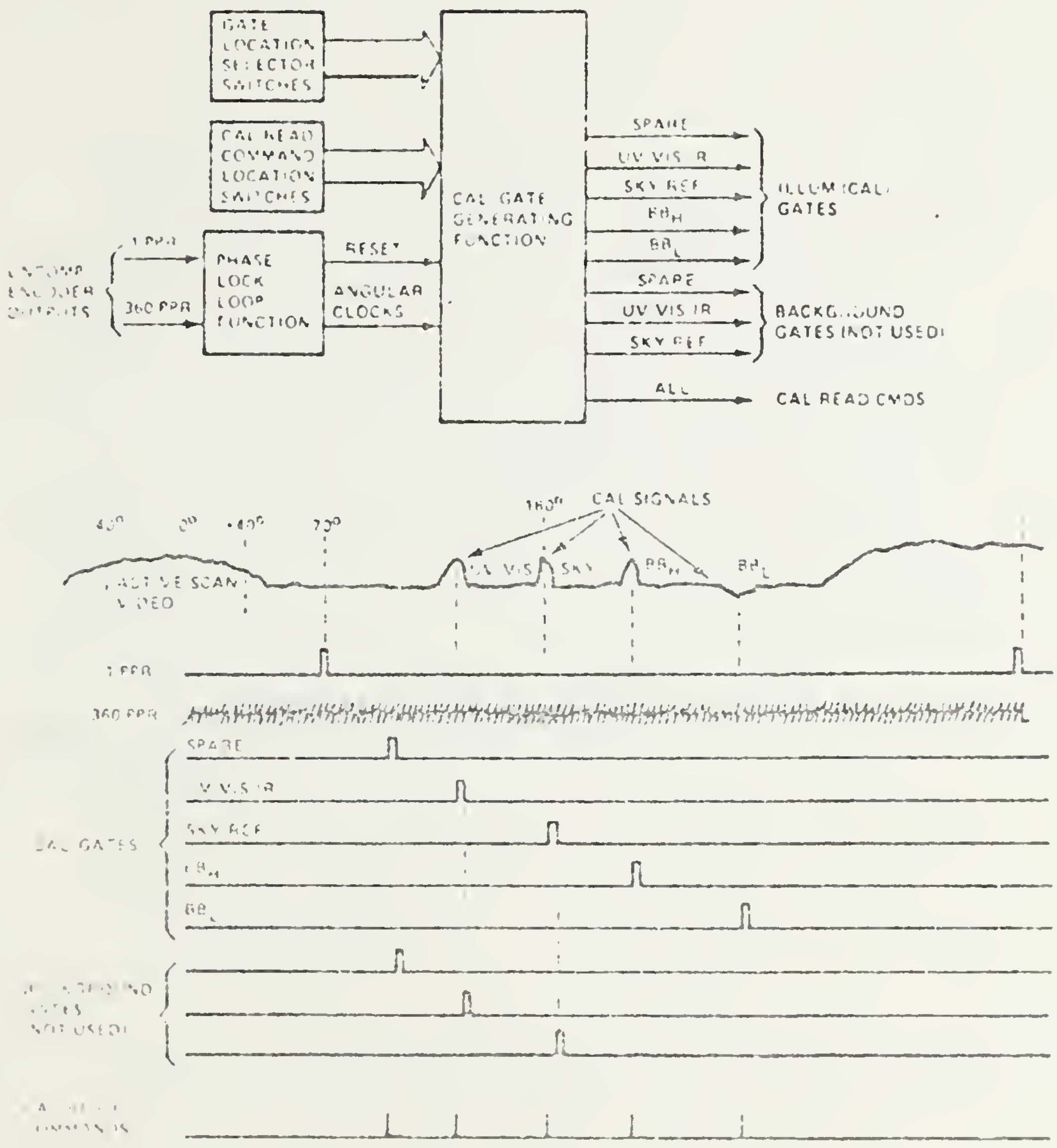


Figure 8. Simplified Theory of Calibration Location Determination

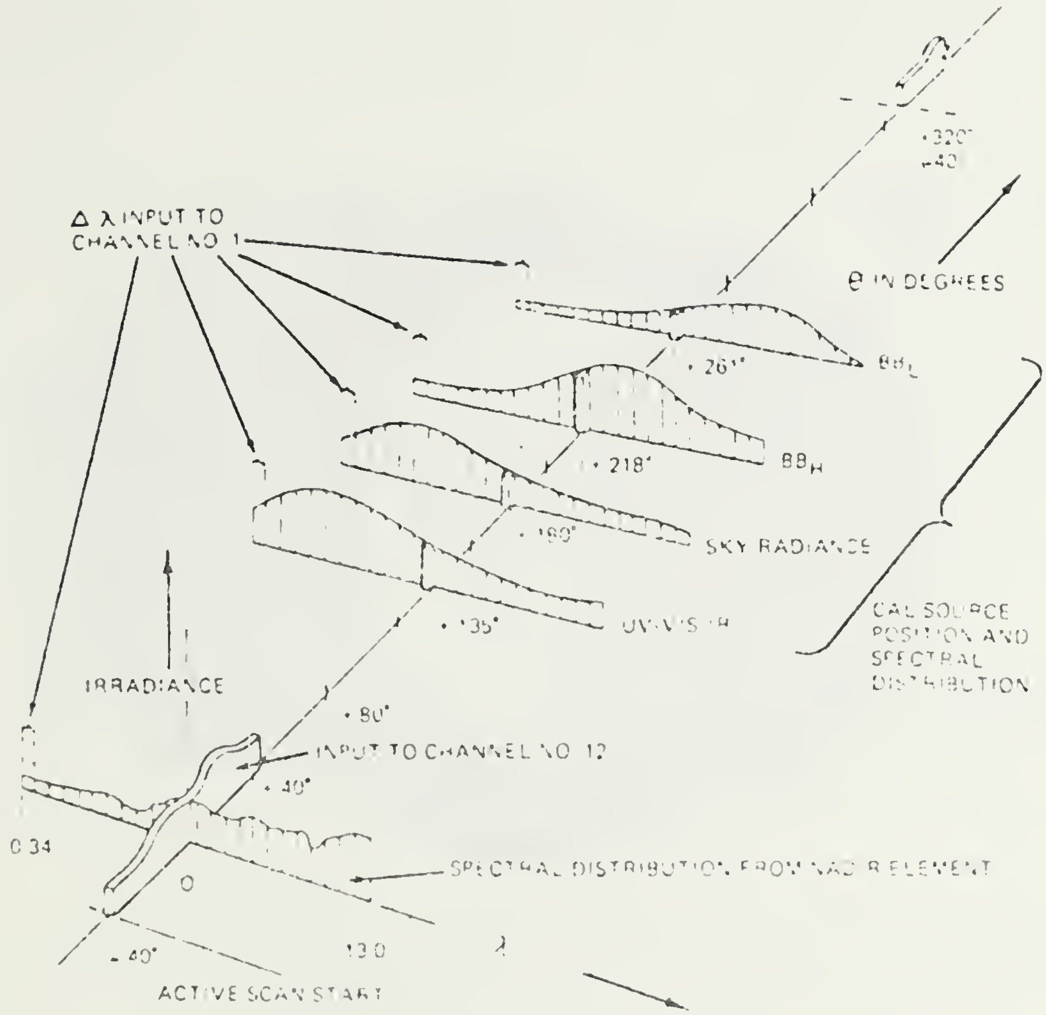


Figure 9. Composite spectral input to scanning optics[5]

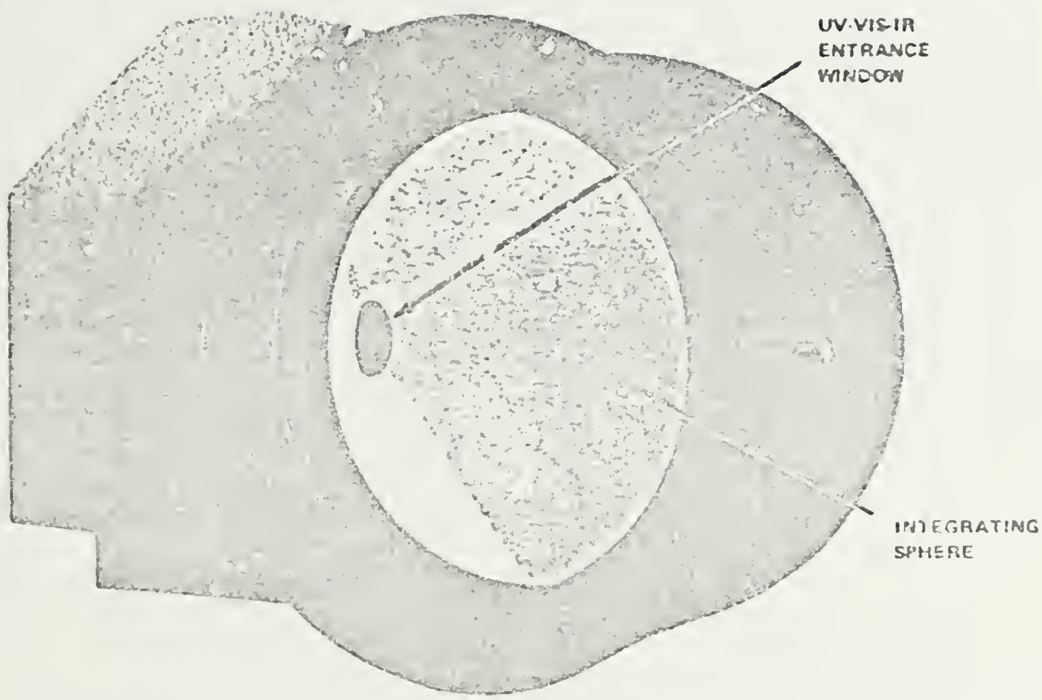
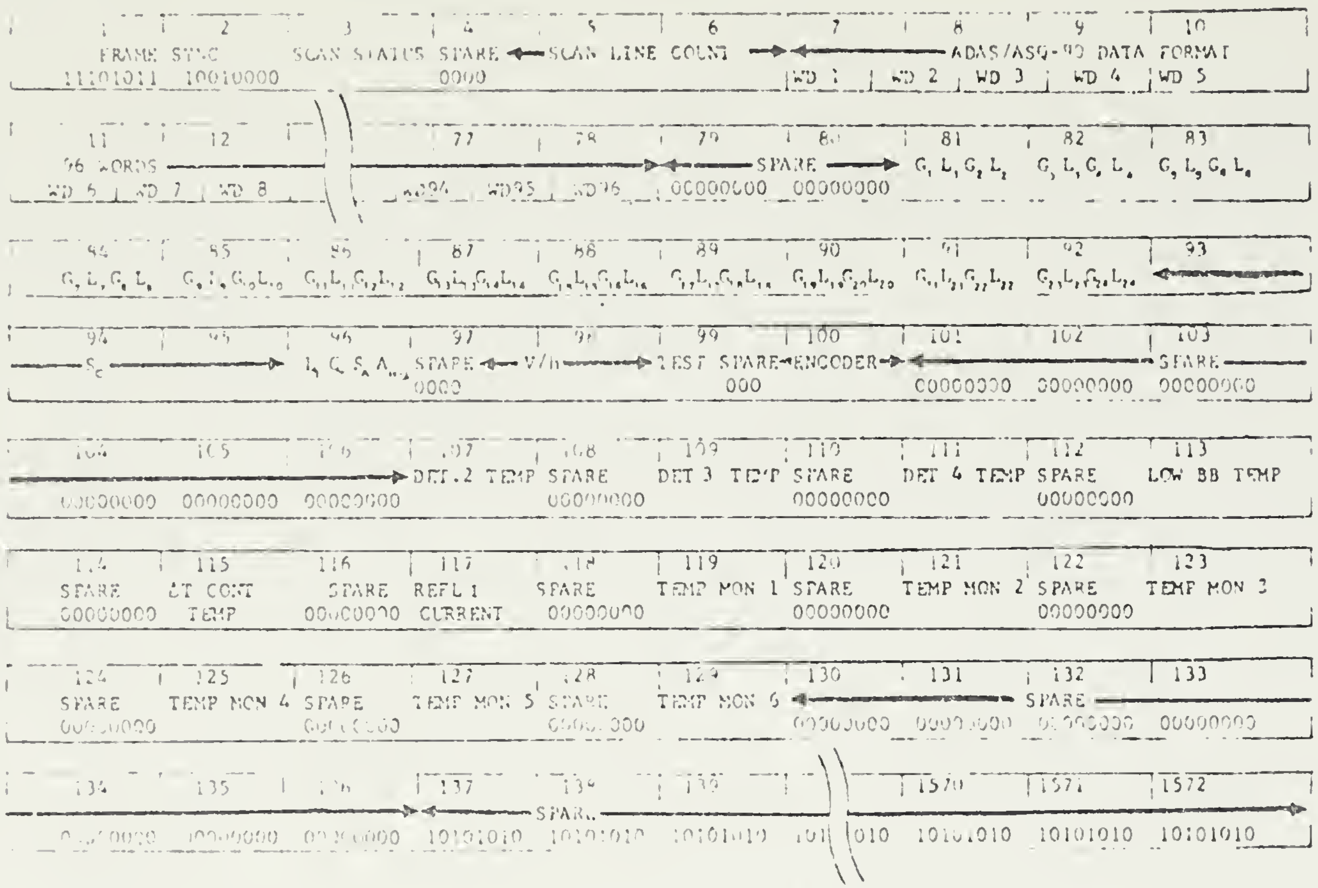


Figure [illegible]. Integrating sphere, UV-VIS-IR (ultraviolet-visible-infrared) in the Bendix 24-channel multispectral sensor system.[5]



G = Voltage Gain, Ch 1-24
L = Voltage Level, Ch 1-24
S_c = Reflectance Calib. Source
0 - Internal, 1-Skylight
L_T = Low Temp Range
C_T^Δ = ΔT Control Temp Range

S_A = Internal Reflectance Source Intensity
A_{RG} Roll-Gyro Allignment State
0-Caged, 1-Uncaged
V/h = Velocity to Height Ratio
0.02 to 0.20 Rad/Sec.
Bit Values Are Given For Only Those Words Whose Values Are Fixed And Cannot Change.

Figure 11. BMSS housekeeping frames[6]

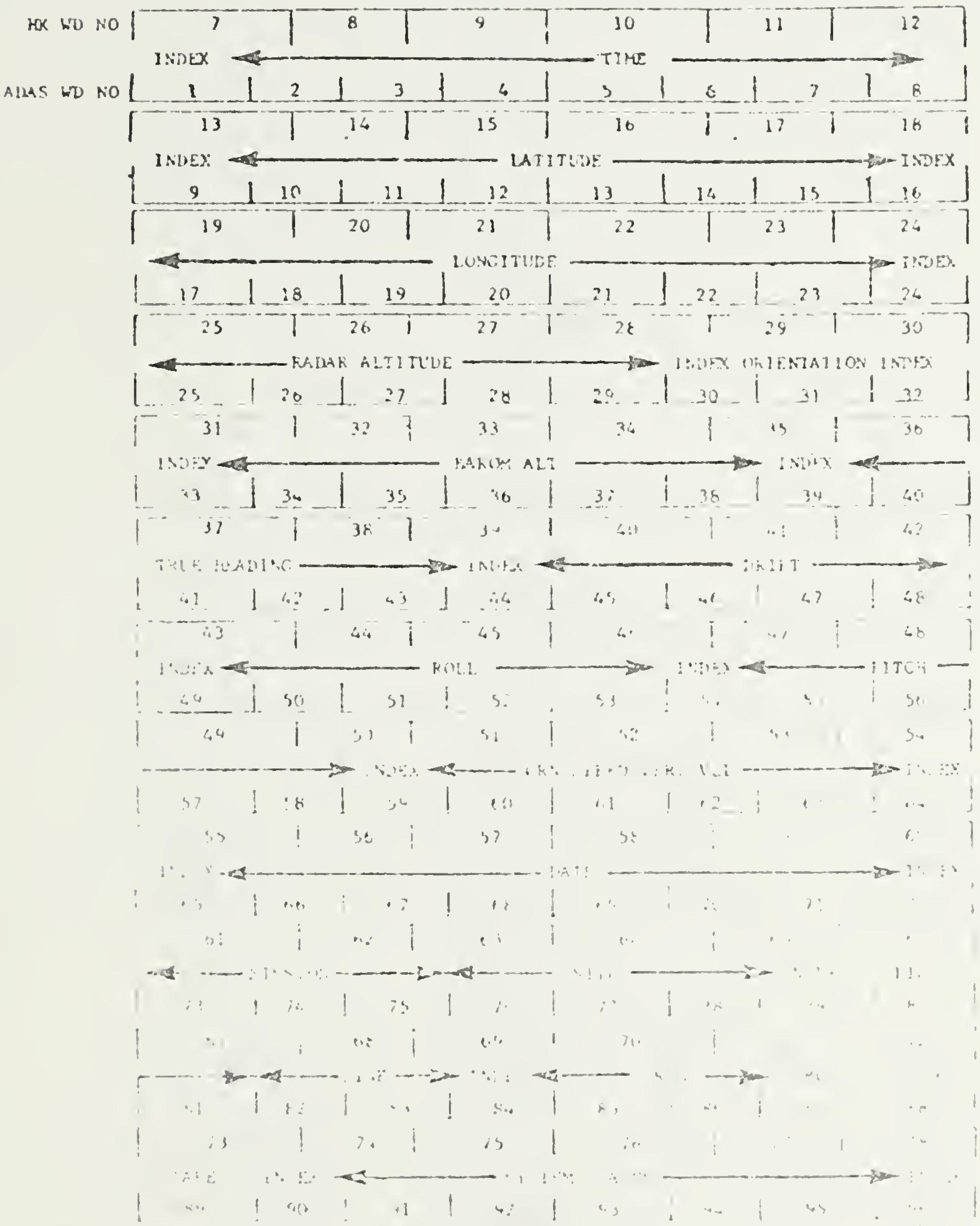


Figure 12. ADAS/ASQ-90 packing in housekeeping words[6]

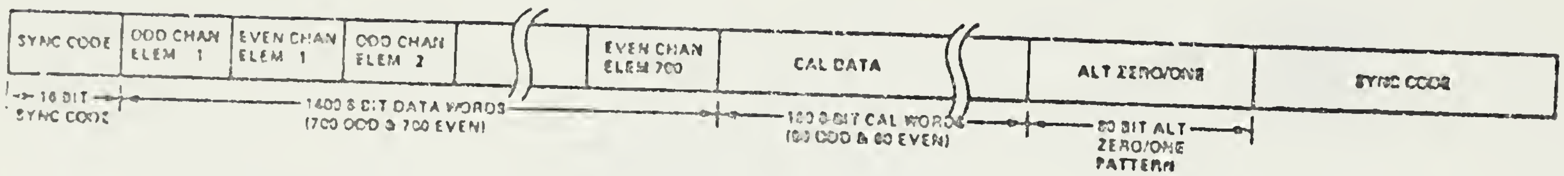


Figure 13. Computer compatible tape format of BMSS data[5]

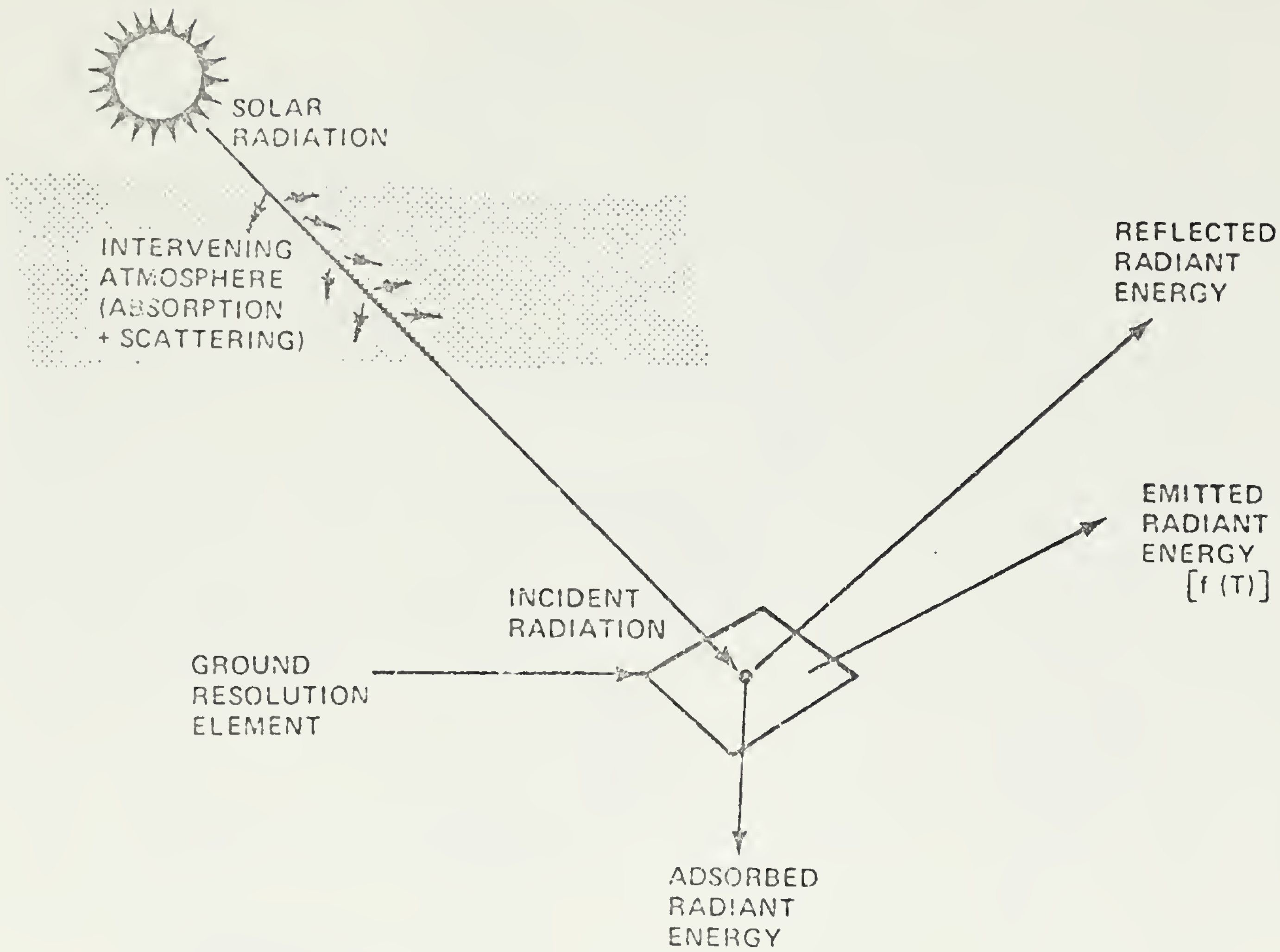


Figure 14. Interaction of radiant energy with matter[5]

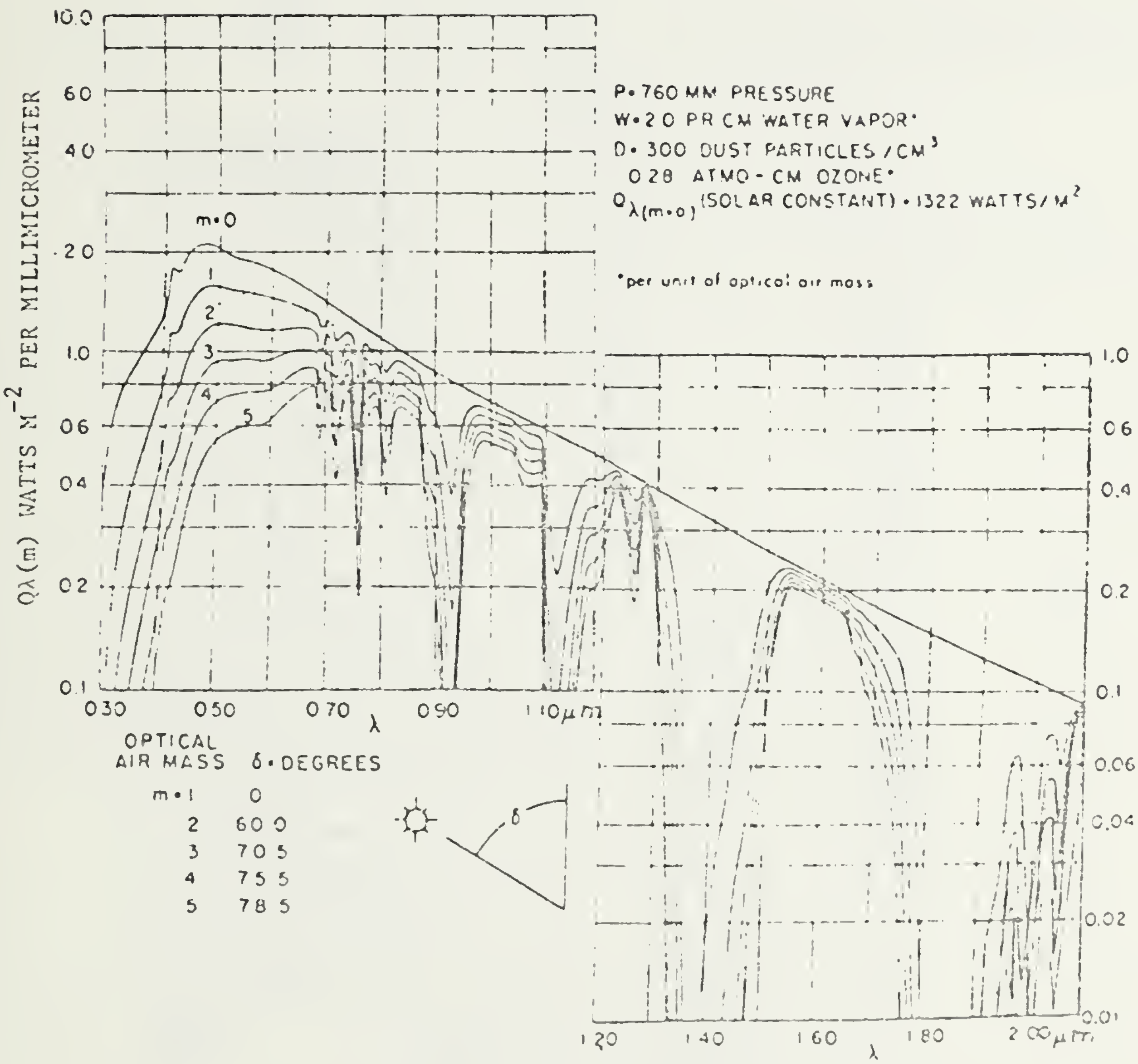
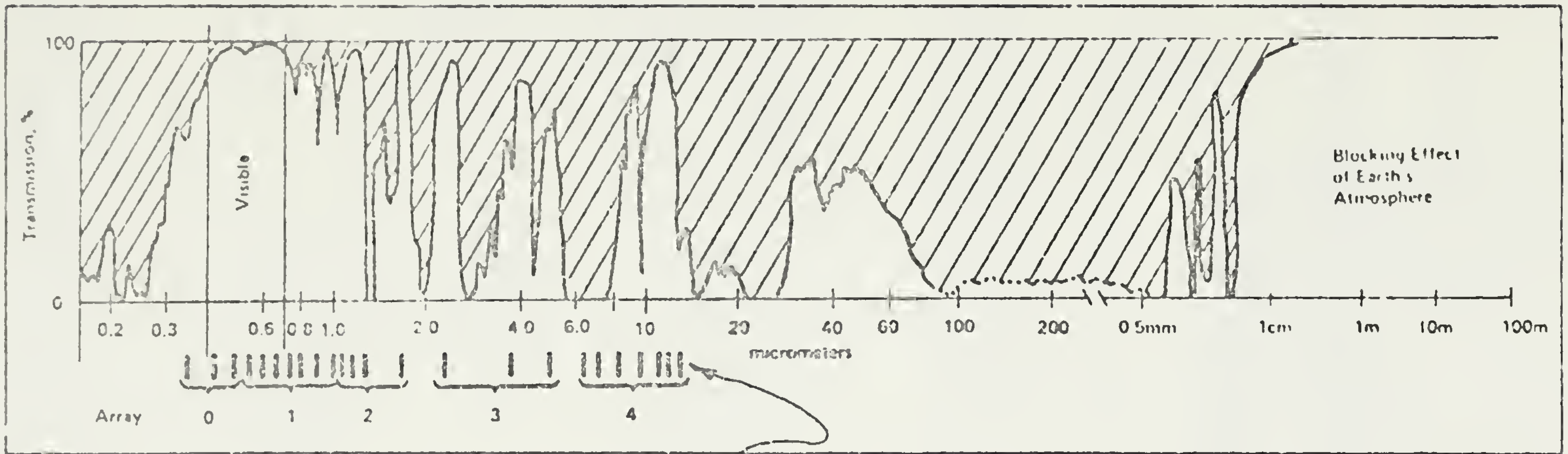


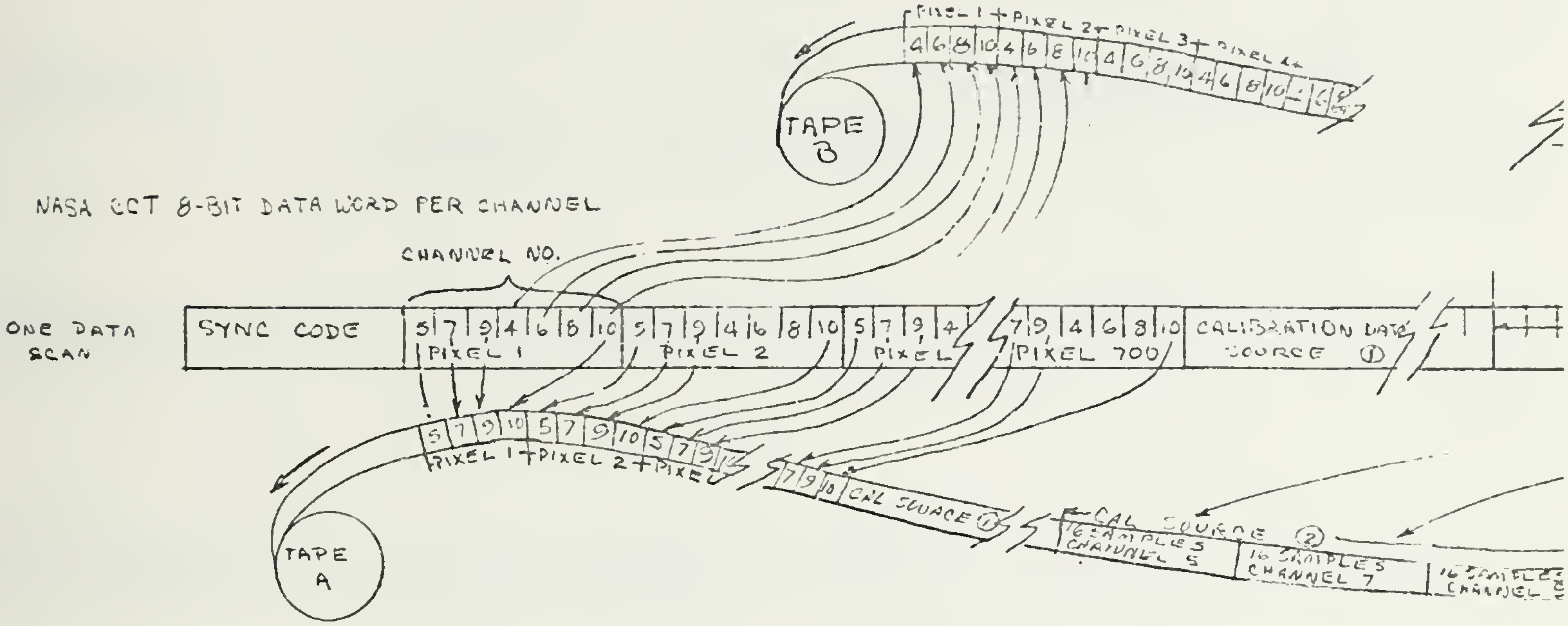
Figure 15. Solar spectral irradiance curves at sea level with varying optical air masses[5]



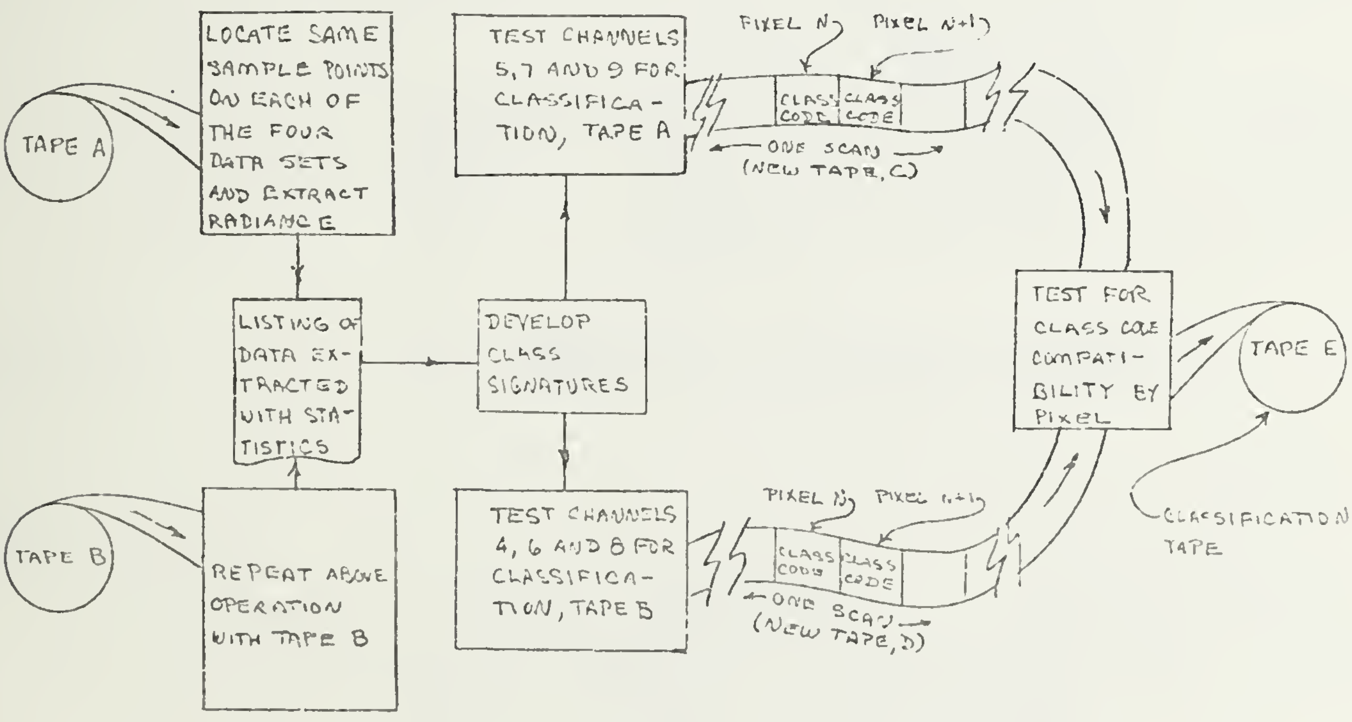
Bar indicates modal wavelength
of a specific channel.

Dectors:
- Array 0 - Photo-multiplier, channels 1-3
- Array 1 - Silicon, channels 4-10, 24
- Array 2 - Germanium, 233°K, channels 11, 12, 23
- Array 3 - Indium antimonide, 77°K, channels 13-15
- Array 4 - Mercury doped germanium, 25°K, channels 16-22

Figure 16. Relations among BMSS wavelength bands and transmission characteristics of the atmosphere (Table 3)



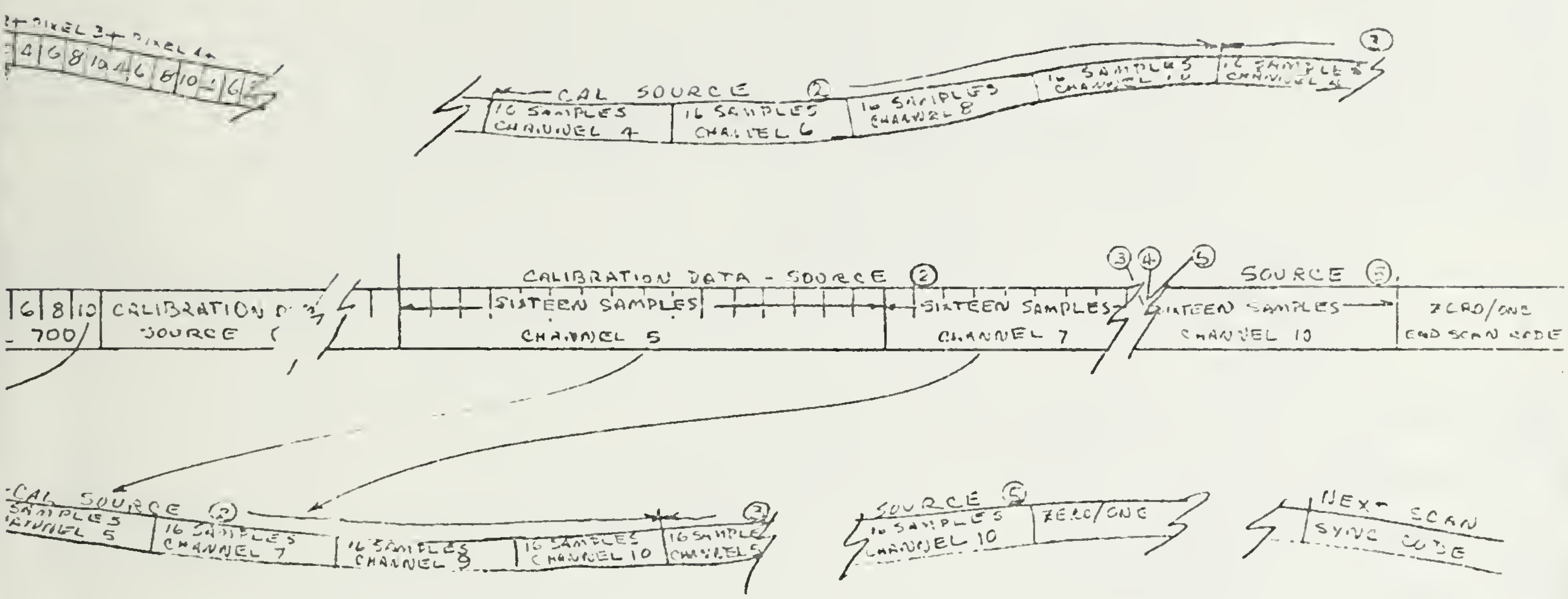
STEP 1 - Extract data in more usable form from NASA CCT.
Extract channels 5, 7, 9, and 10 on one tape
and 4, 6, 8, and 10 on another. Include
appropriate calibration data at end of each scan.

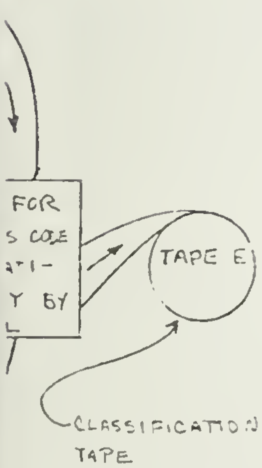


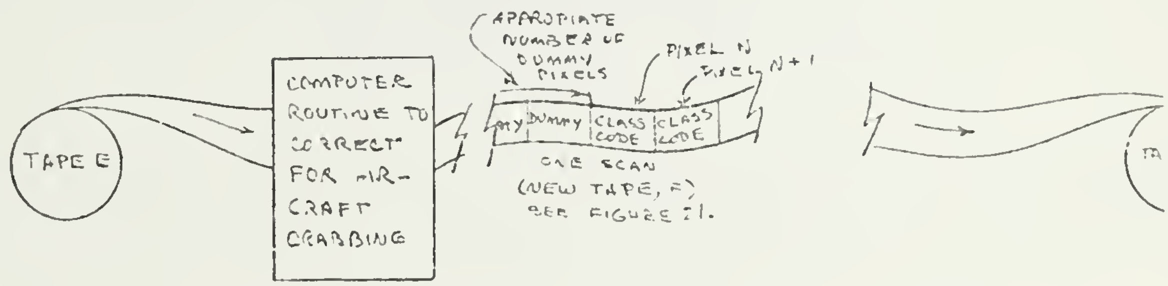
STEP 3 - a. Write two intermediate classification tapes
using ERTS program.

b. Using a special 24-channel program, merge
the two intermediate tapes to produce one
classification tape.

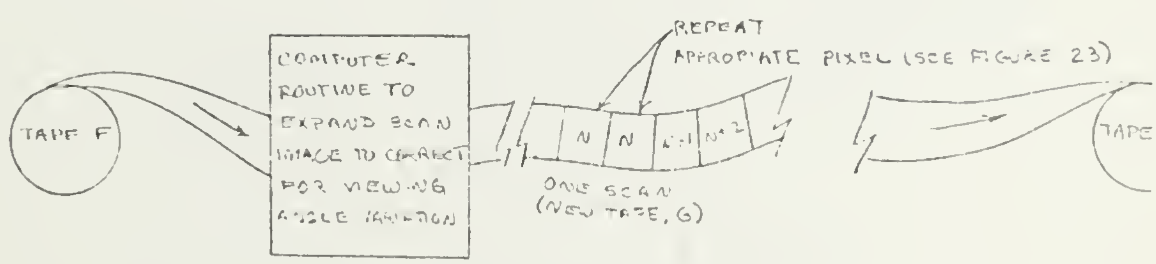
Figure 17. ERTS procedure, showing re





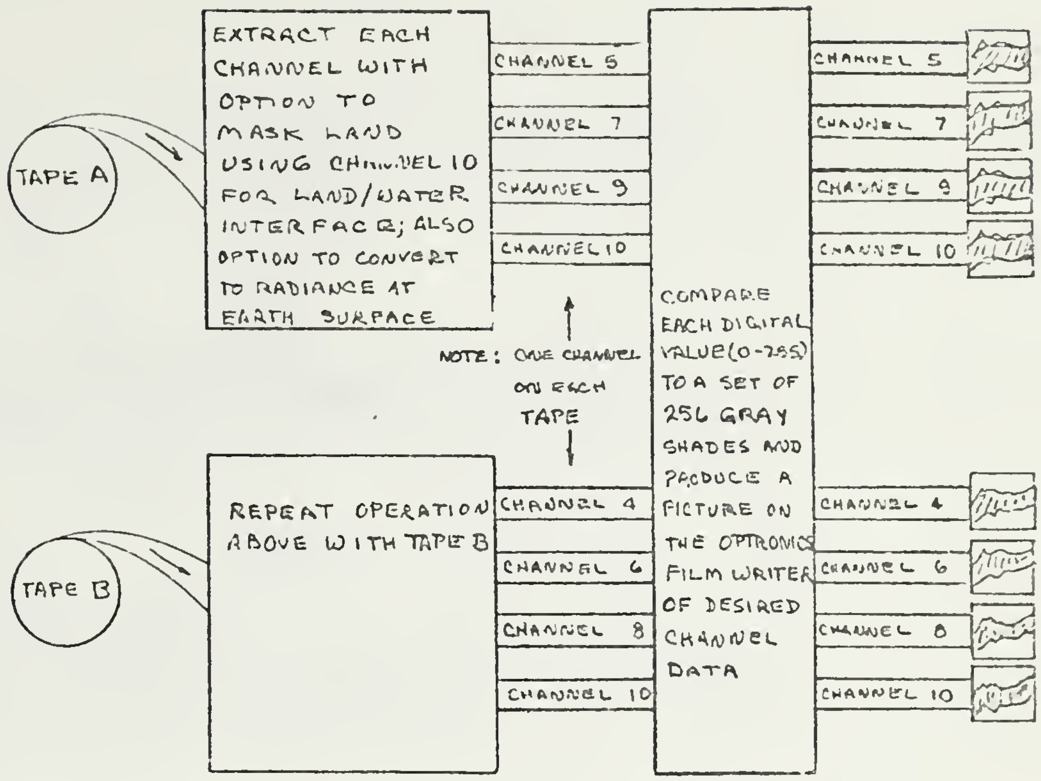


STEP 4 - Apply 24-channel program to correct for crabbing (essentially a skewing technique in the direction of line of flight). A new tape is produced.



STEP 5 - Apply 24-channel program to expand scan image producing a new tape.

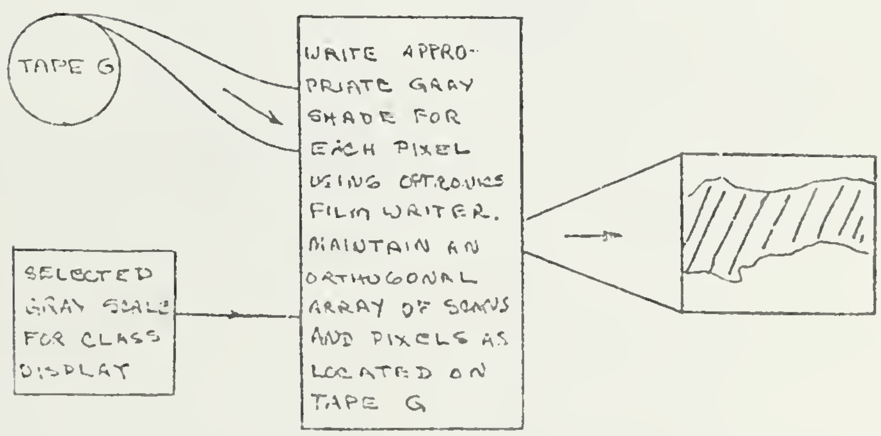
17. WES procedure, showing required data formats, to produce a picture with the Optronics film wri



STEP 2 - a. Rewrite tape data in format for ERTS programs on hand, masking land if desired.

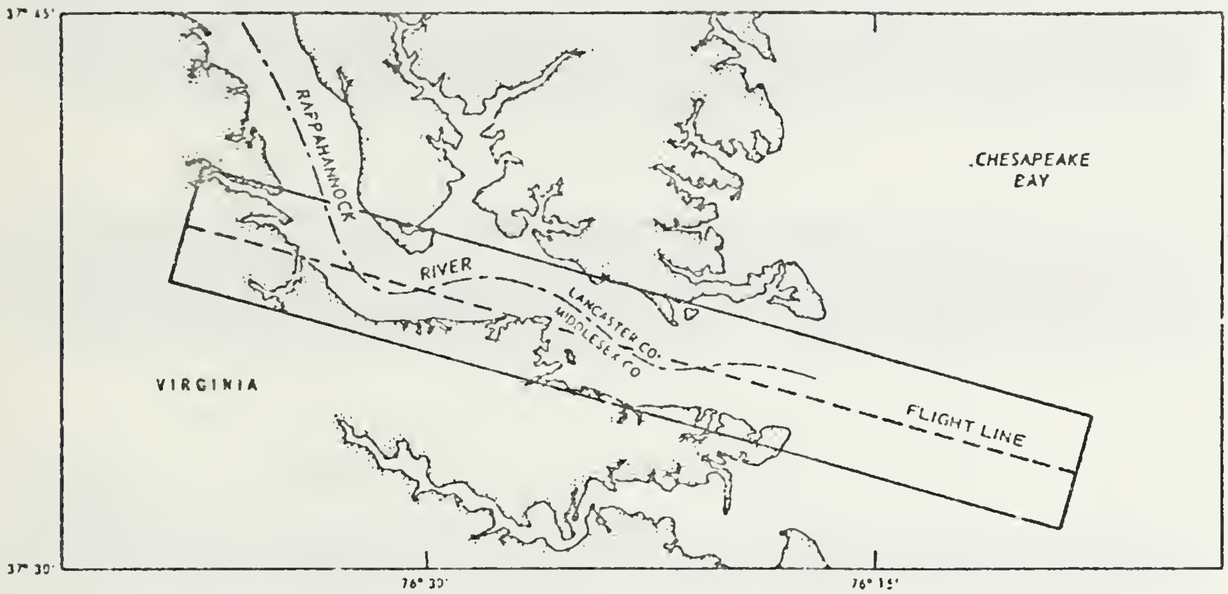
b. Apply 24-channel algorithm to convert digital tape data to radiance at earth surface as new tapes are written (if desired).

c. Produce desired digital pictures from any channel data by coding the digital data (0-255) to 256 shades of gray on the optronics film writer.

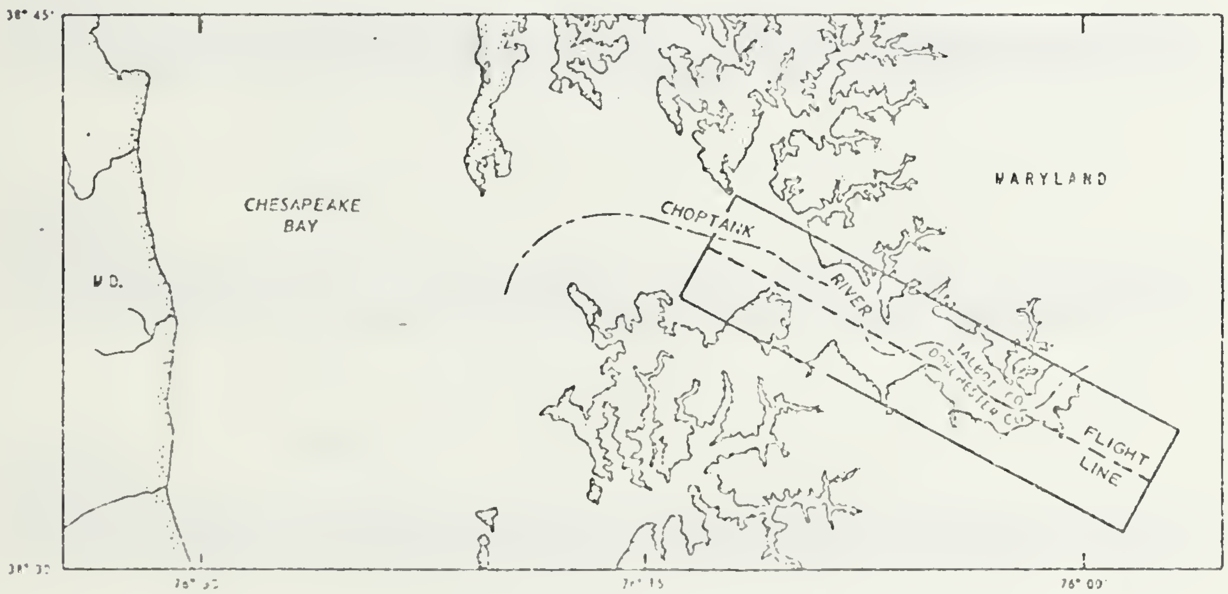


STEP 6 - Write and develop film interpreting digital codes into shades of gray.

Optronics film writer from 24-channel data



a. FLIGHT LINE 3 - LOWER RAPPAHANNOCK RIVER, VIRGINIA



b. FLIGHT LINE 6 - LOWER CHOPTANK RIVER, MARYLAND

Figure 18. Flight line locations (Mission 218 and Mission 230)

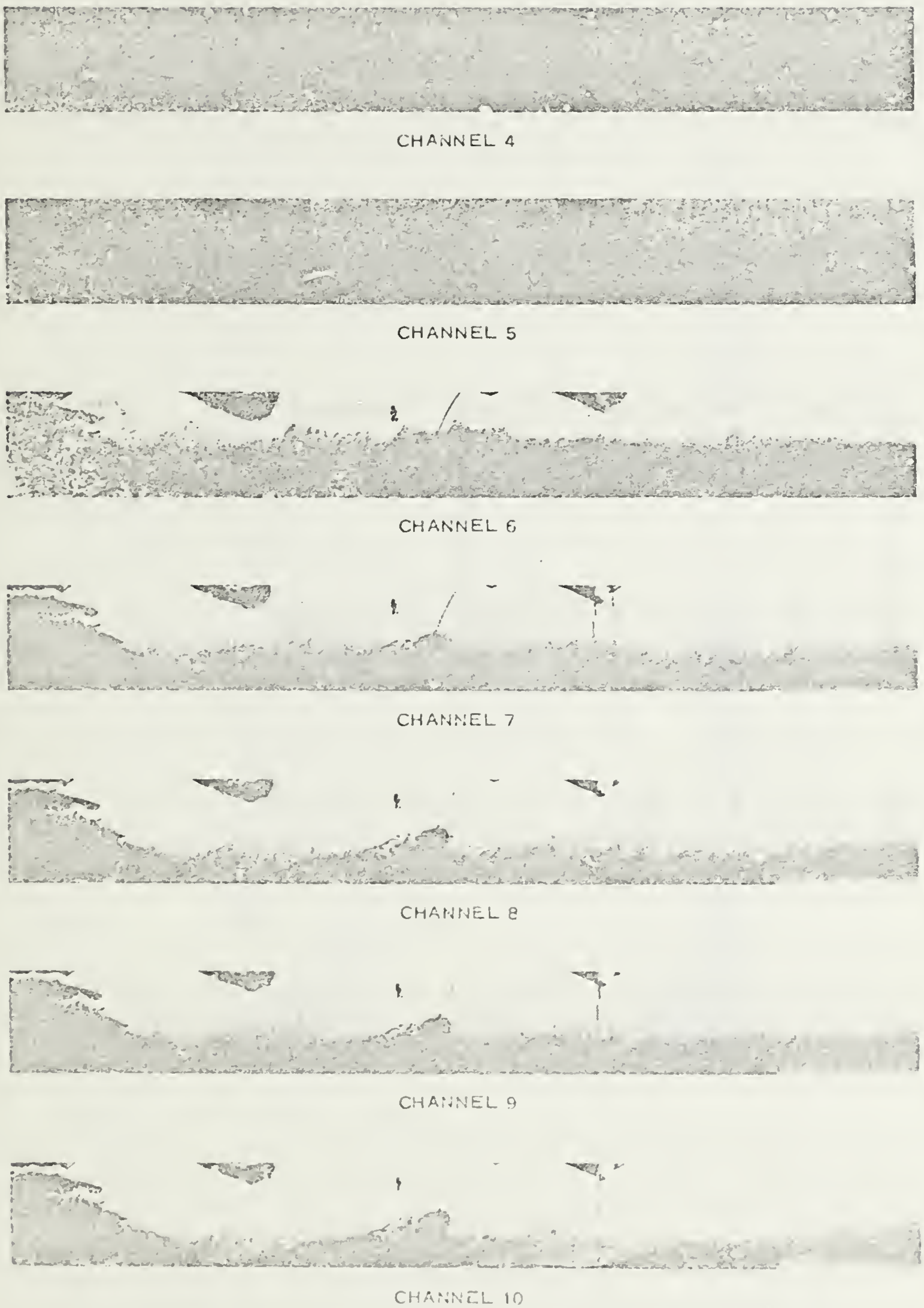
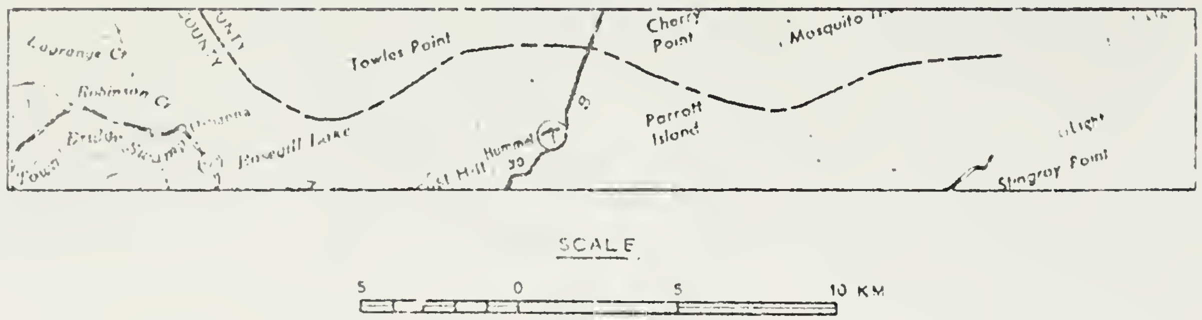


Figure 19. Film written from digital CCT data (0-255), Rappahannock River, Mission 230, 22 April 1973



a. TOPOGRAPHIC MAP - 1:250,000

b. OPTRONICS FILM WRITER MAP USING CHANNEL 10 DIGITAL DATA (FIGURE 19)

Figure 20. Lower Rappahannock River

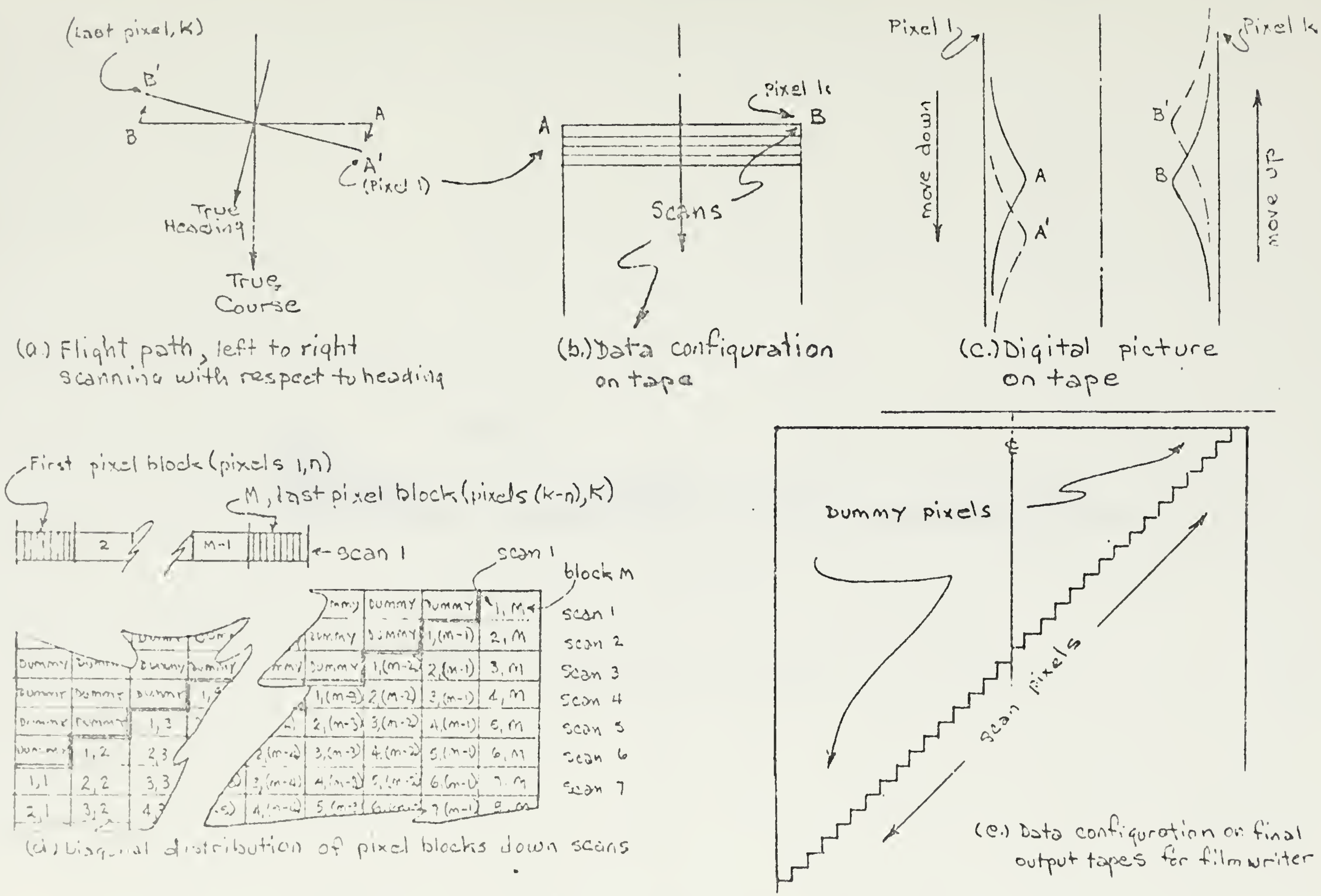


Figure 21. Data correction procedure for aircraft crabbing

Figure 22. Rappahannock River, after correction for aircraft crabbing

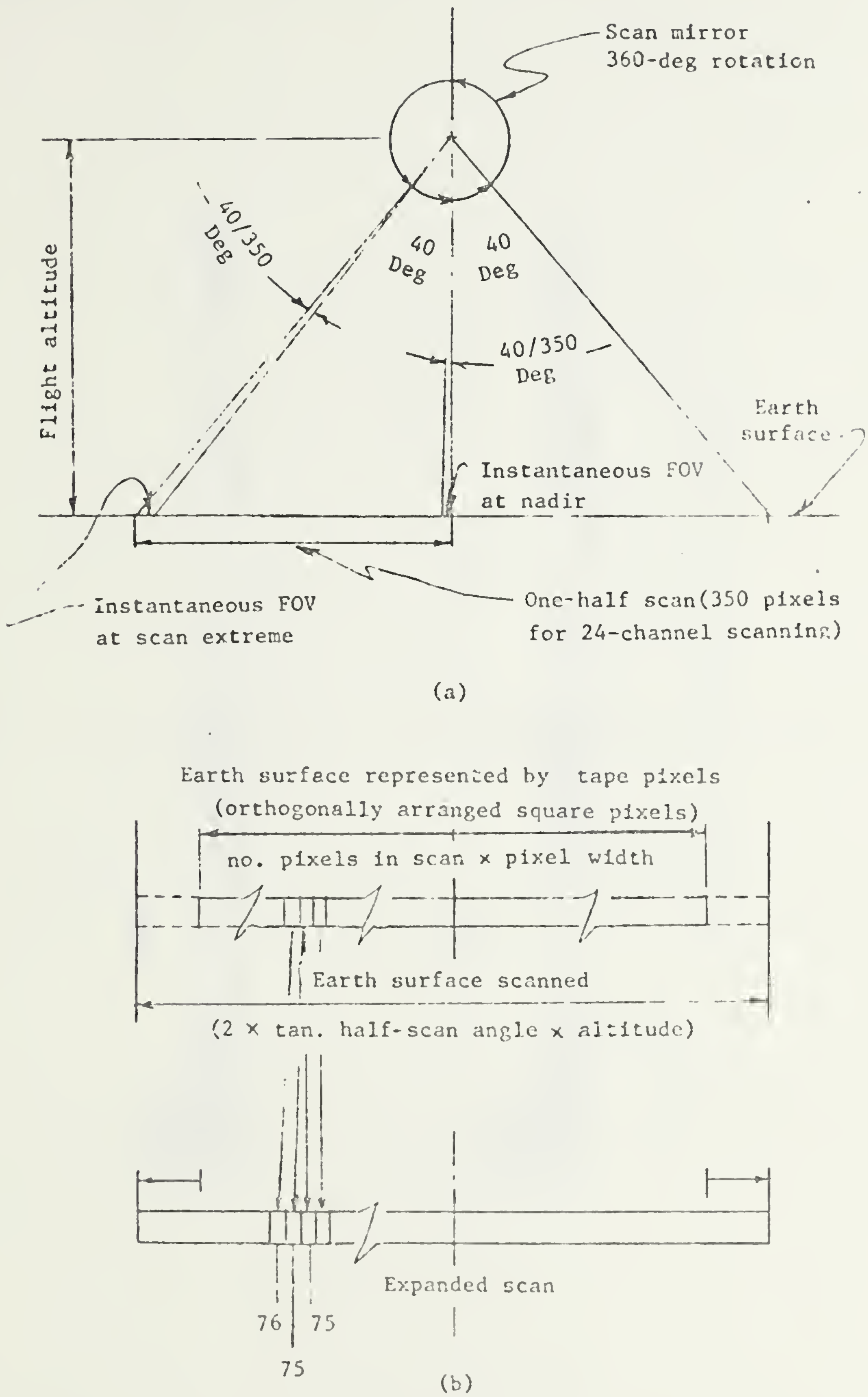


Figure 23. Correction procedure for registering scan extremes

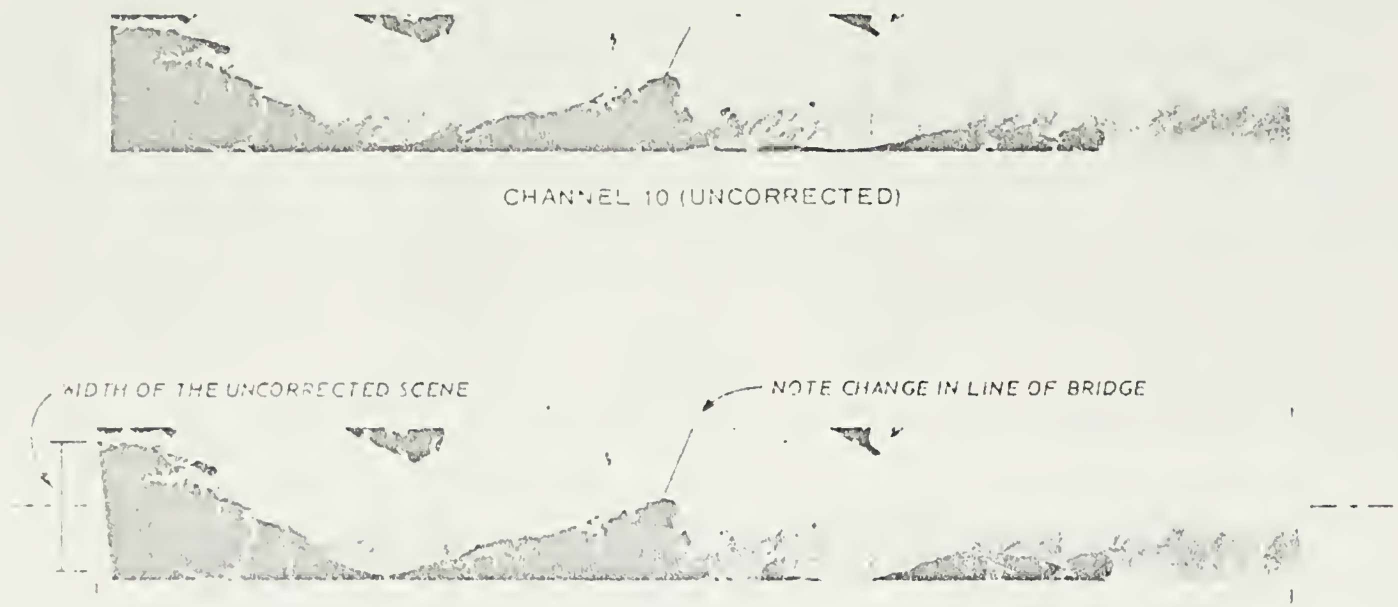
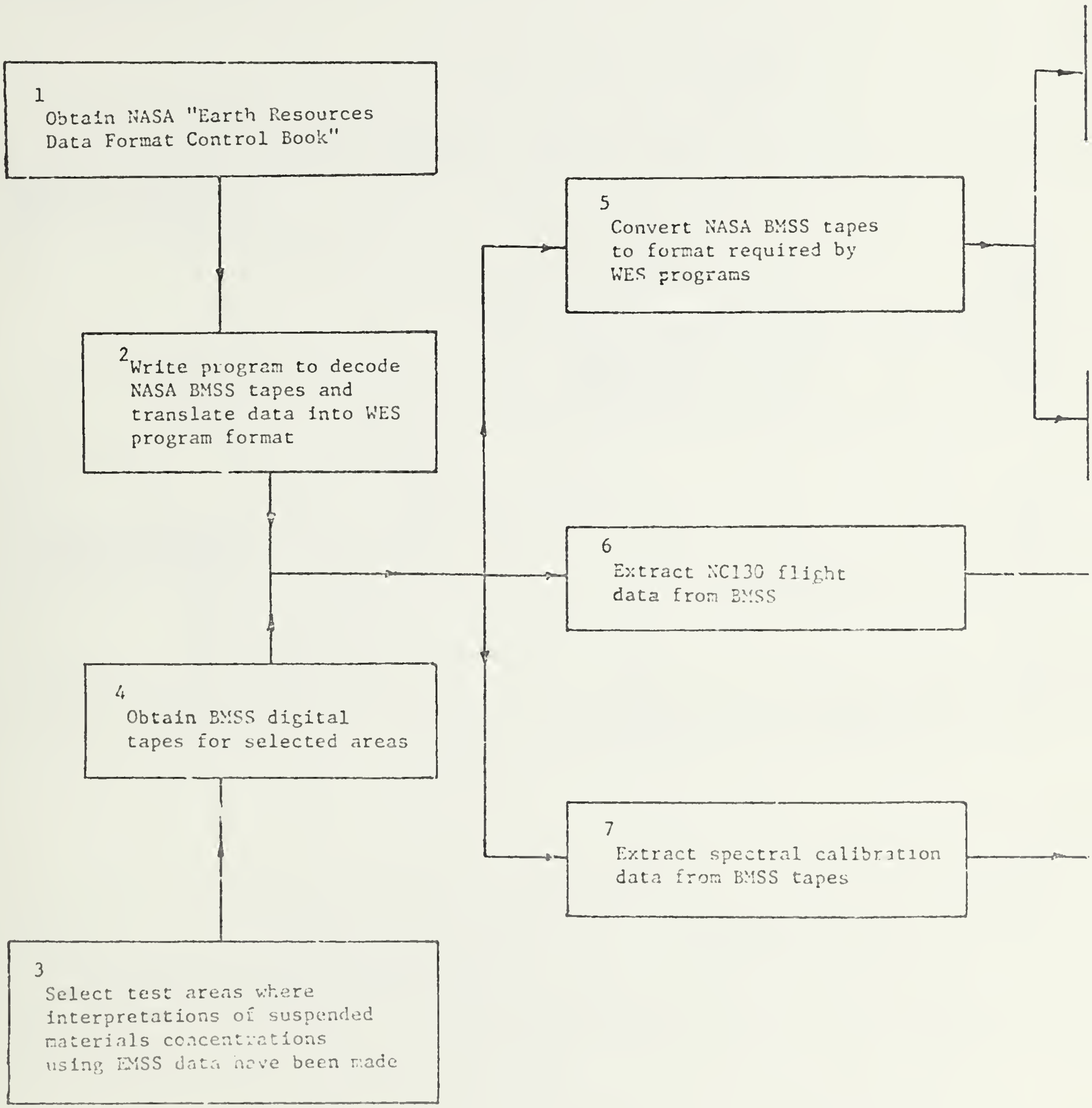
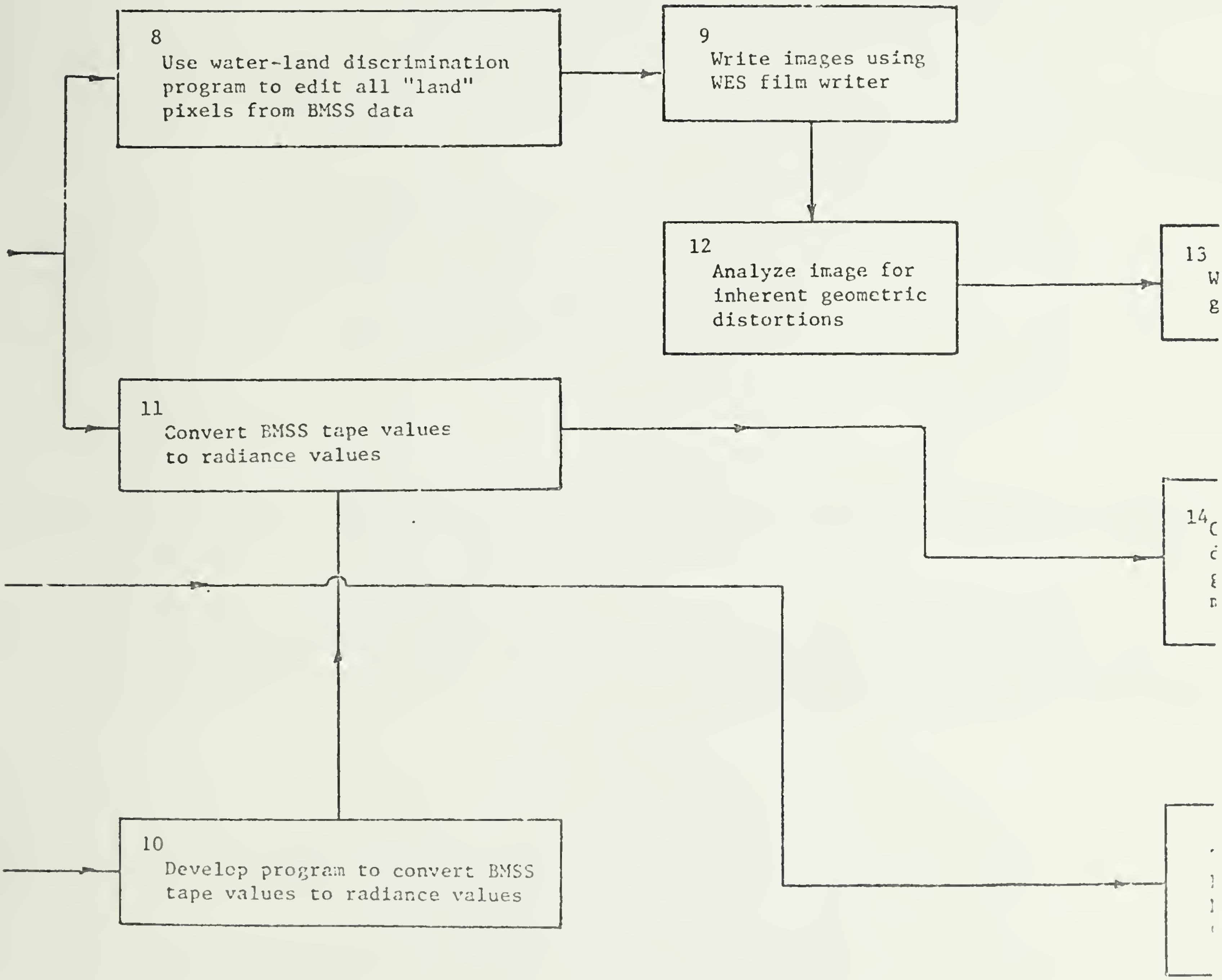
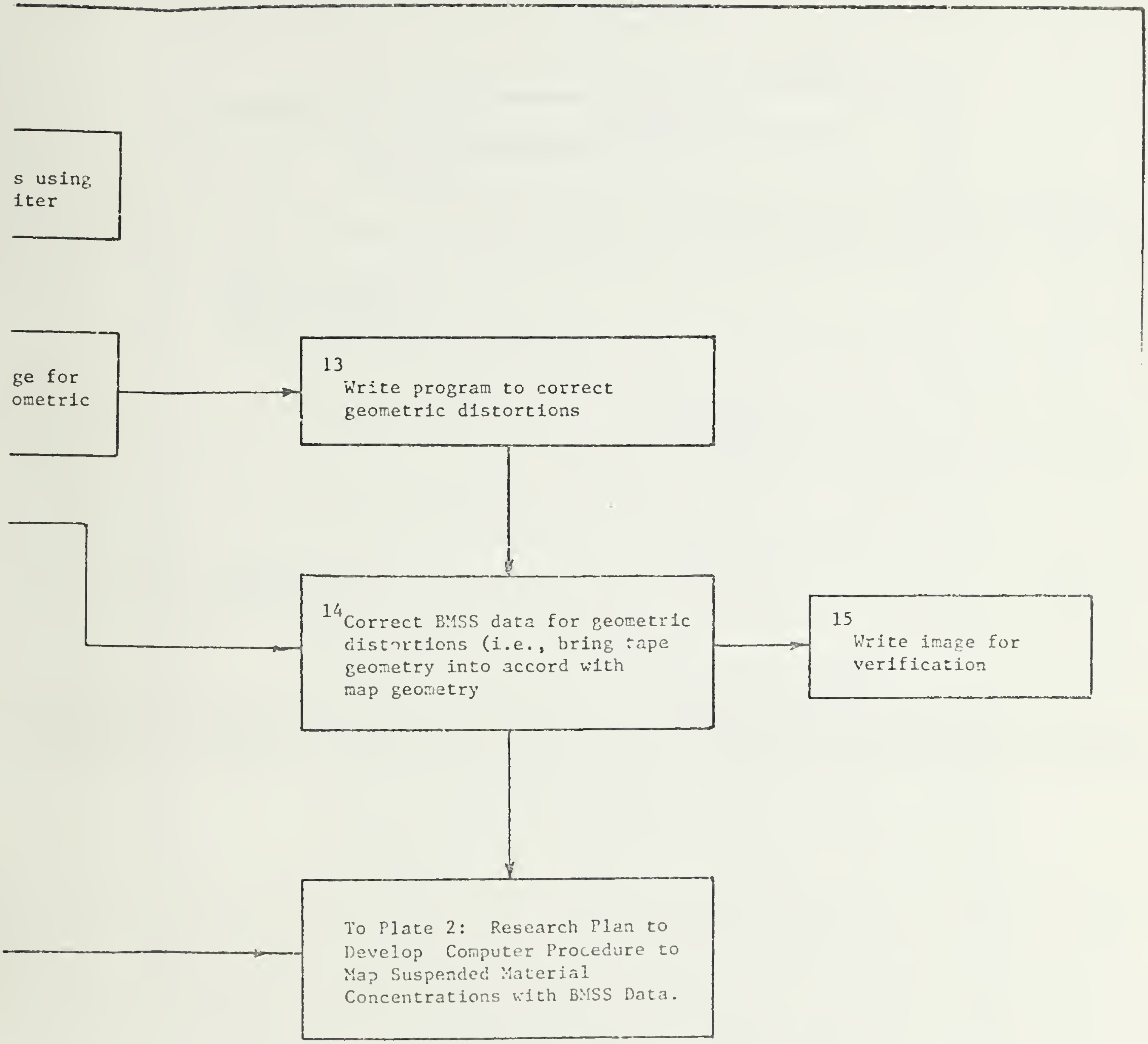


Figure 24: Rappahannock River, comparison of before and after corrections for crabbing and viewing angle

Primary Objective: Plan to Develop Data Handling Procedures




8
Use water-land discrimination program to edit all "land" pixels from BMSS data
9
Write images using WES film writer
12
Analyze image for inherent geometric distortions
13
11
Convert BMSS tape values to radiance values
14
10
Develop program to convert BMSS tape values to radiance values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Write program to correct geometric distortions
14
Correct BMSS data for geometric distortions (i.e., bring tape geometry into accord with map geometry
15
Write image for verification
To Plate 2: Research Plan to Develop Computer Procedure to Map Suspended Material Concentrations with BMSS Data.

Secondary Objective. Plan to Develop Computer Programs to Map Suspended Materials Concentrations with BMSS Data

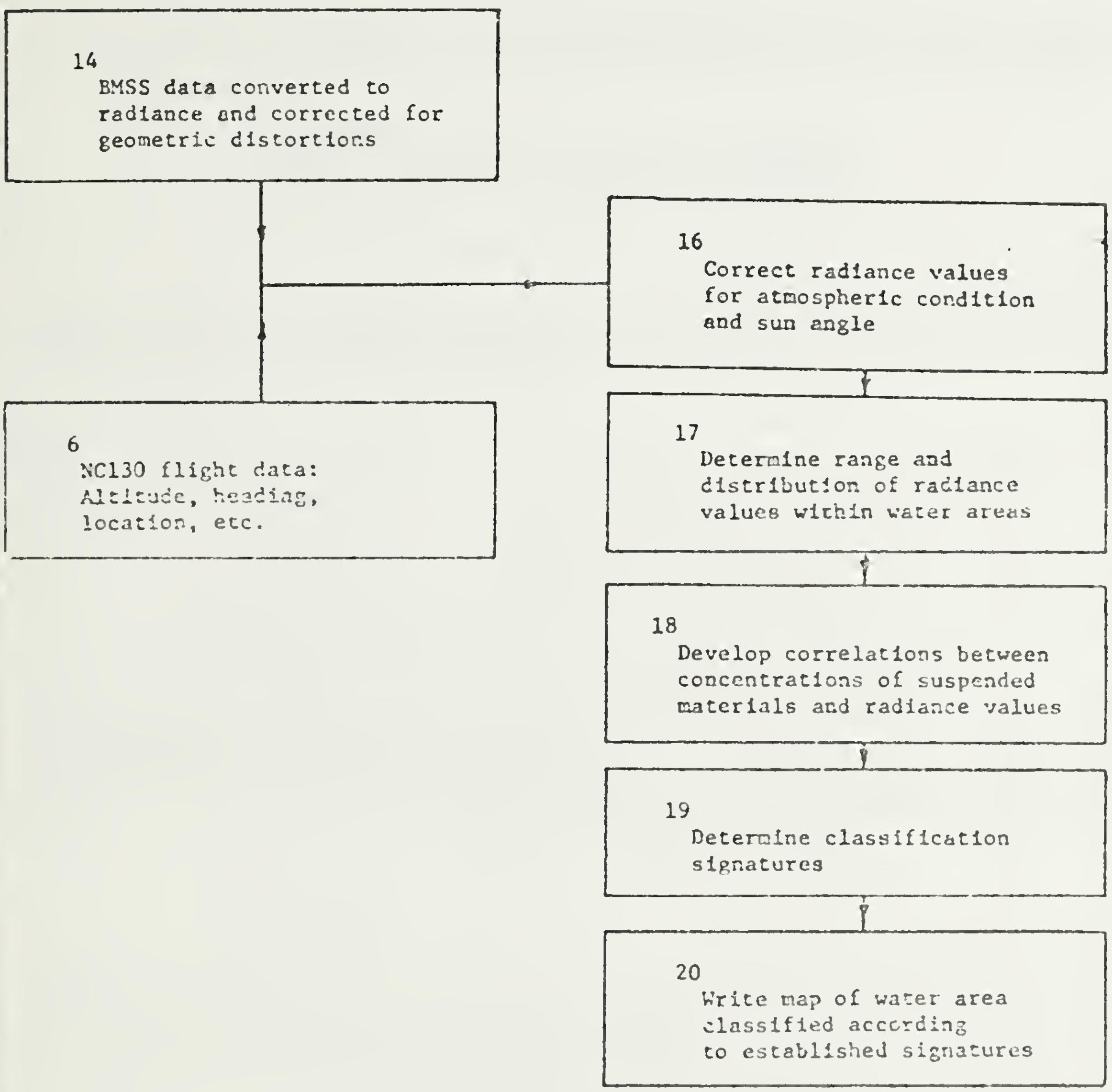

PLATE 2

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Smith, Margaret H
Feasibility of monitoring flow patterns and sediment and pollutant dispersion of water bodies with 24-channel spectral data. by Margaret H. Smith. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper M-76-10)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project 6.11.01A, 4A061101A91D.
Includes bibliography.

1. Chesapeake Bay. 2. Data processing. 3. Pollutant dispersion. 4. Rappahannock River. 5. Remote sensing. 6. Sediment. 7. Sensors. 8. Water flow. I. U. S. Army. Corps of Engineers. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper M-76-10)
TA7.W34m no.M-76-10

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